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USE OF REMOTE SENSING IN AGRICULTURE

by David E. Pettry, Norris L. Powell, and Michael E. Newhouse

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DEPARTMENT OF AGRONOMY
VIRGINIA POLYTECHNIC INSTITUTE
AND STATE UNIVERSITY
Blacksburg, Virginia 24061

For

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
WALLOPS STATION
Wallops Island, Virginia 23337
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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ABSTRACT

This report describes the work performed for the NASA-Wallops-VPI & SU contract "Remote Sensing in Agriculture" during the first three years of the project. A review of the literature related to the use of remote sensing in agriculture is presented. The report deals with the remote sensing studies at the Virginia Truck and Ornamentals Research Station near Painter, Virginia, and other Chesapeake Bay areas to investigate soil and plant conditions via remote sensing technology. Twenty-nine remote sensing flights were flown over the Painter Station between August 1969 and September 1973 utilizing multispectral imagery. Detailed ground truth data were recorded and relevant environmental variables were measured for each flight.

In 1972 studies were extended to include the Tidewater Research and Continuing Education Center, the Eastern Virginia Research Station, the Hundley and Blackwell farms near Warsaw, Virginia, the peanut Cylindrocladium black rot disease plots near Suffolk, Virginia, the Southern Peidmont Research and Continuing Education Center, the University of Delaware soil fertility demonstration plots near Millsboro, Delaware, and the University of Maryland Research Station near Salisbury, Maryland.

The imagery data for the flights flown between 1969 and 1972 have been evaluated and the results are given in this report. The imagery data for 1973 are presently being evaluated.

Remote sensing techniques and interactions are discussed in the report. Specific studies on the effects of soil moisture and organic matter on energy reflection of extensively occurring Sassafras soils are discussed. Greenhouse and field studies investigating the effects of chlorophyll content of Irish potatoes on infrared reflection are presented. Selected ground truth and environmental monitoring data are shown in summary form. Practical demonstrations of remote sensing technology in agriculture are depicted and future use areas are delineated.

FOREWARD

This report covers work performed from July 1970 through June 1973 under Contract Number NAS6-1863 for the National Aeronautics and Space Administration, Wallops Station, by the Department of Agronomy at Virginia Polytechnc Institute and State University. This is an interim report and gives the progress of the research work for the first three years of the project. It is anticipated that the project will continue for at least three more years and that by then more conclusive results will be available for publication in a formal report.

The contract to study the applications of remote sensing in agriculture was formally initiated July 14, 1970. The objectives of this project were initially formulated to investigate, develop, and evaluate a system to study a controlled agricultural research station and the forestry growth along the periphery using remote sensing techniques. These investigations were to utilize multi-spectral photographic techniques to (a) identify plant canopies; (b) detect elemental deficiencies and disease; (c) detect plant growth; (d) study soil recognition and classification; (e) study irrigation effects; and (f) study forestry growth.

The research approach and methodology have been directed to develop and refine basic techniques, to establish parameters of the systems involved, and to determine relationships of soil-plant interactions that are significant to remote sensing. This research approach includes aircraft flights over specific test sites to collect airborne data (color and color infrared imagery). Extensive ground truth data has been collected during the flights over each test site. This ground truth data includes soil type and temperature, soil moisture content, added nutrients, cultivation data, plant canopy, ground evaluation of plant vigor, vegetational map, and additional information as required. This ground truth and airborne data have been integrated into a remote sensing program to develop a system of remote sensing most useful for agriculture, forestry, and land use.

At the present time work is continuing on evaluating the last three years of data on preparing papers for publication.

This report gives recommendations for work which should be carried out over the next three years.

A review of the literature dealing with remote sensing related to agriculture revealed that most of the related literature was less than five years old and all of the related literature was no more than a decade old.

Acknowledgement and gratitude are extended to Mr. R. L. Kreiger, J. H. Scott, Jr., Dr. J. D. Oberholtzer and other National Aeronautics and Space Administration personnel for their outstanding cooperation and individual assistance with this research effort. Acknowledgement is extended to Dr. E. M. Dunton, Jr., Virginia Truck and Ornamentals Research Station, Painter, who was instrumental in initiating this cooperative project.

INTRODUCTION

During the last three years numerous aircraft flights have been flown over several test sites in Virginia, one test site in Maryland, and one test site in Delaware. During each flight, relative ground truth data was recorded for the site involved. Fig. 1 indicates the general areas where the test flights were flown. They include the Virginia Truck and Ornamentals Research Station at Painter, Virginia, the Tidewater Research and Continuing Education Center at Holland, Virginia, and the Eastern Virginia Research Station at Warsaw, Virginia, as primary test sites. Other test sites where flights were flown and data collected are the Hundley and Blackwell farms near Warsaw, Virginia, the peanut Cylindrocladium black rot disease plots near Suffolk, Virginia, the University of Delaware soil fertility demonstration plots near Millsboro, Delaware, the University of Maryland Research Station near Salisbury, Maryland, and the Southern Piedmont Research and Continuing Education Center at Blackstone, Virginia. A description of each test site and the research being conducted at each location are discussed in this report.

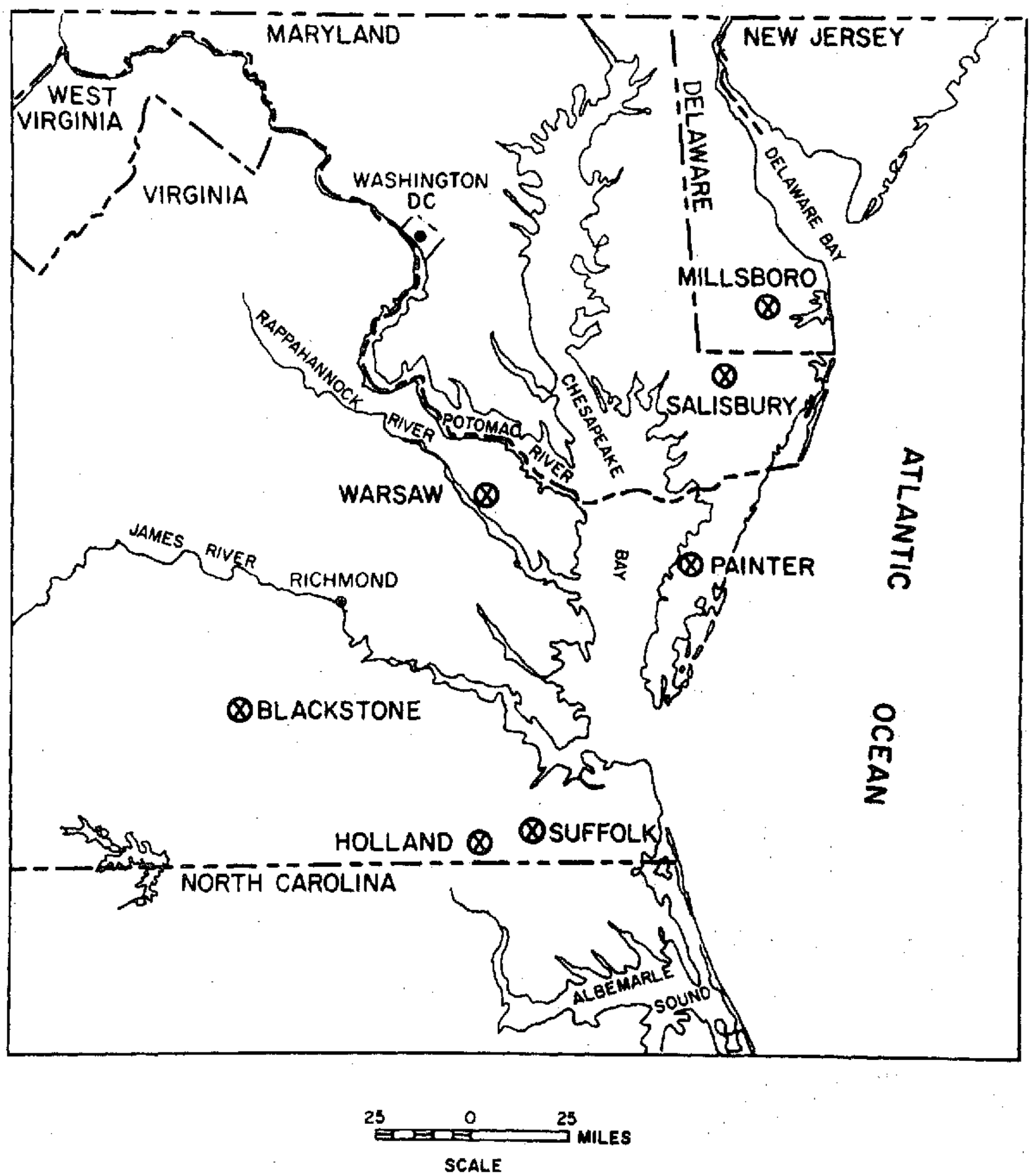

Fig. 1. Geographical locations of study areas.

LITERATURE REVIEW

The earth receives radiation from the sun in wavelengths extending from hard gamma rays to long radio waves. Of the total radiation, 99% occurs in the wavelength region 0.295 to 10 micrometers; more than 50% of the total occurs at wavelengths greater than 0.71 micrometers. Most plants are adapted to reflect a high percentage of the radiation in the infrared region which prevents them from becoming too warm during the day. It is this reflective and some emissive properties of plants and other bodies which had led to the use of remote sensing. Even though the development of infrared film and thermal recorders are an important part of remote sensing, one should not overlook the fact that conventional films also play a role in this field of research. Because of the selective reflectance and absorbance of plants and soils remote sensing has become an important tool for the agricultural manager.

Remote sensing might be defined as the use of a sensor at a distance to obtain information about an object or condition without coming into physical contact with that object. The sensors available have multiplied in the last decades; both passive and active systems have been used.

Cameras have been improved; film spectral response has been extended to the near infrared; optoelectronic images have been developed that record a registered image in many spectral intervals, from the ultraviolet through the infrared, simultaneously. Nonscanning radiometers have been used to measure spectral intensity from the ultraviolet through the microwave. Side looking radar has been flown to obtain a microwave image of a target. Laser systems in aircraft have identified fluorescent targets on the surface. Concurrent with the development of sensors, analysis techniques have become more powerful; in particular, computer aided recognition procedures have been shown to be an important analysis tool. Platforms for the sensors have also been expanded; a variety of aircraft carry the instruments from just above the surface to tens of kilometers in altitude; spacecraft extend the altitude to hundreds and thousands of kilometers at which valuable information is received and transmitted to the investigator.

The useful electromagnetic spectrum for agricultural remote sensing is usually thought of as extending from the ultraviolet to the microwave. This wide interval may then be divided according to the technique used to record the radiation. From the ultraviolet to the near infrared, 0.3 to .9μm, photographic film is sensitive; and many special films exist to emphasize particular spectral regions, color infrared (or false color) film, for example, is commonly used to record growing plants because of its excellent response to the infrared reflected from leaves. Multispectral scanners can also cover this spectral region; their output is recorded serially rather than in parallel (as in a camera) thus they are a more computer compatible sensor. As is known, short wavelengths are preferentially scattered in the atmosphere causing a loss of contrast; many systems for high altitude and space work will omit the spectral region below about 0.5μm. For wavelengths longer than .9μm optoelectronic sensors must be used; however, not all wavelengths are useful because of absorption due principally to water vapor and carbon dioxide. There is an atmospheric window at approximately 2-5μm and another extending from 8-14μm; both of these windows can be used for thermal measurements, that is, for emitted radiation rather than reflected. At longer wavelengths the atmosphere is essentially opaque until the microwave region is reached where electronic techniques developed mostly for radar are used to detect the radiation. Relatively little work has been done in the microwave region compared to the visible and infrared. This report deals exclusively with the visible and infrared.

Infrared radiation can be separated into four ranges of increasing longer wavelenghts (Kodak Technical Publication M-28). The techniques to measure the four types of radiation falls into two broad catagories: those using conventional and infrared film and those involving complex auxiliary equipment which converts the radiation into an electrical signal. Infrared film is used to record the first type of radiation (.720-1.000 microns). At the present time longer wavelengths are impossible to record because of the damage to the film from stray radiation of humans and other objects. Thermal infrared recorders and systems have been developed which gives images for the various wavelengths.

The development of infrared film is an important factor in the use of remote sensing in agriculture. This type of film was first used to detect camouflage. Tarkington and Sorem (1963) and Fritz (1967) described the difference between Kodak Ektachrome Infrared Aero Film, Type 8443 and conventional color film. Unlike the conventional color film, which has layers sensitive to blue, green, and red radiation, the infrared (IR) film has the blue layer replaced by an IR sensitive layer. All three layers are sensitive to blue light, thus a yellow filter is used to remove the blue light which also removes the effect of haze. This filtering property in the IR range is now being utilized to study forest fires through smoke cover.

Factors Affecting Multispectral Photography and Thermal IR Recordings

Colwell (1961) first stated that image tone or color was a function of five important variables. These variables were: (1) the spectral sensitivity of the film or detector, (2) the spectral transmittance of the filter, (3) the spectral distribution of the energy source, (4) the spectral scattering by atmospheric haze particles, and (5) the spectral reflectance and/or emittance from the object. Lauer (1969) later used the five variables in a study of factors affecting multispectral scanning. He found that the first two variables (camera and filter system) offer the researcher an opportunity to select wavelengths which will give the most desirable results. Film and filter systems, and thermal scanners and recorders are available which will cover a very narrow wavelength range. The third variable, spectral distribution of the energy source, is quite variable and care must be taken to obtain maximum results. The sun is the sole energy source for multispectral photography; therefore, photos should be taken during cloudless mid-day hours to insure a compatable spectral distribution of energy. However, Northrop and Johnson (1970) found that photos of forest stands taken with black and white IR film gave better detail taken under a high overcast. Thermal IR recorders also measure the reemitted energy which is stored by most bodies. Since most plants and other objects reemit energy at different wavelengths and at a different time of the day, a consideration must be given to the time of recording. Neubert (1969) found early morning gave the most significant difference in temperature between sick and healthy trees, but Myers and Heilman (1969) found night hours the most satisfactory for measuring soil temperature variations.

The fourth variable, atmospheric effects, has been nearly eliminated through filtering systems. Blue light (400-500 millimicrons) is scattered more than any other radiation; therefore, a minus blue filter (Wratten 15) reduces the haze interference. Transmission of thermal IR radiation through the earth's atmosphere is extremely efficient.

The final variable, the spectral reflectance and/or emittance from an object has received the most attention in the literature. Characteristics of plants, soil, water, etc. affecting reflection or emittance are quite variable and a great deal of research is still needed in this area.

Factors Affecting the Reflection of Plants and Soils

Benedict and Swidler (1961) measured the reflection of various leaves at wavelengths up to 1.0 micron for soybeans and valencia orange. They found only slight variations in percent reflection for leaves of various chlorophyll contents in the IR range. Measurements at 625 millimicrons were used to construct a curve of percent reflection over percent chlorophyll.

Fritz (1967) found wide variation in reflection values between plant species. Grass species reflected over 80% of the radiation at 720-900 millimicrons, birch 50%, pines 35%, and true fir 18%. This indicates that cell and leaf structure influence reflection more than differences in chlorophyll content.

Greenhouse studies by Ward (1969) and Richardson et al. (1969) found no effect of drought, high salt, and four nutrient deficiencies on percent reflection of leaves of maple, corn, squash, and sorghum at wavelengths of 800, 1000, or 1200 millimicrons. Reflection increased at 530 and 640 millimicrons only after visible chlorophyll reduction occurred. Species reflection differences also showed only a slight variation. A possible reason for the lack of variation in reflection in the IR region was given by Gausman et al. (1969a). He found strong evidence that plants grown in the greenhouse develop shade type cells and leaves which have similar reflective properties. Weber and Olson (1967) found that moisture conditions during leaf development affect its reflective properties. Leaves of tree species which developed during satisfactory moisture conditions have the same reflective property regardless of moisture stress after full development. However, leaves developing under various conditions of moisture stress will later show variations in reflection.

The effect of leaf age of cotton was determined by Gausman et al. (1969b). Leaves tagged as soon as visible increased in reflectance (0.50-2.50 microns) up to 12 days; after 12 days reflectance decreased. He concluded that reflectance increased because of an increase in number of intercellular spaces in the leaf mesophyll. An increase in percent water content might also be a contributing factor, but the drought study of Ward (1969) tends to discount this factor.

Gausman et al. (1970) found the tonal response on Ektachrome infrared aero film was darker red for Cycocel-treated plots than for untreated plots. They attributed this to increased chlorophyll contents (darker green color) in leaves of Cycocel-treated plants, which reduced the reflectance of visible light, causing denser yellow and magenta positive images in the film layers sensitive to green and red radiation.

Carlson et al. (1971) reported that leaf structure and water content constitute major factors affecting the interaction of radiant energy with leaves. They measured reflectivity and transmissivity in the wavelength region from .8 to 2.6 microns for leaves from corn, soybean, and sorghum. There was a highly significant relationship between relative leaf water content and the spectral response over four wide-wavelength intervals.

Weber and Polcyn (1972) reported on the applications of airborne multispectral remote sensing and the potential of automatic multispectral processing as a means for previsual detection of damage from insect infestation, disease organisms, and oxidant air pollution. They speculated that the availability of simultaneously registered data covering the entire bandwidth in narrowband increments with optical-mechanical line scanners should yield improved accuracy.

Knipling (1970) found that the primary basis for the detection of stress conditions in a crop or other plant community by aerial remote sensors often is not a change in the reflectance characteristics of individual leaves, but a reduction in the total leaf area exposed to the sensors. This reduction could result from a direct loss of leaves, a change in their orientation, or an overall suppression of plant growth.

This limited literature indicates that reflection differences (and hence photographic color and tone) between species is more dependent on leaf and cell structural differences than on chlorophyll variation in the IR range. Reflection in IR of leaves of a species is not affected by moisture stress or nutrient deficiency if the leaves developed under adequate moisture regimes. However, any factor which reduces the chlorophyll content of the leaf will decrease radiation absorption and increase reflection in the visible region.

Soils vary tremendously in their ability to reflect and reemit radiation. Condit (1970) measured the reflectance of 285 surface soils (2") at wavelengths of 300-1000 millimicrons. He found that wet soils reflect 2 to 3 times the reflectance of dry soils at wavelengths between 600-100 millimicrons. Characteristic curves were found for different soil textures, but no soil series names were given. Myers and Heilman (1969) used a thermal infrared recorder to measure temperature variations between various soil conditions. High soil moisture, greater clay content, and low soil air contributed to low soil temperatures and smaller fluctuations. The maximum diurnal temperature for dry fields averaged 45-51°C and irrigated fields 40-42°C. Night hours gave the widest variations in soil temperatures and should be used when scanning soil or water conditions.

Another variable which may reduce the quality of thermal IR images is the condensation of moisture on the mirror of the scanner. Williams (1969) used a thermal IR recorder in studies over the desert, the artic, and Puerto Rico.

No problems occurred until flights were made over the humid region of Puerto Rico. Dropping only a few hundred feet in the humid area caused condensation on the mirror. This occurred when the mirror's surface temperature dropped below the dew point temperature of the ambient air. Quality of images were reduced because of scattering of the radiation by the water droplets. He feels that this may also be a problem in the humid regions of the United States.

Detection of Disease, Insect, and Pollution Damage

Remote sensing is now commonly used for the detection of crop or tree damage throughout the world. Conventional films have been used for several years with limited results. Manzer and Cooper (1967) compared conventional aerial color and panchromatic film, and color and black and white infrared film for identifying areas of severe defoliation from late potato blight. Only severe defoliation could be seen on conventional film, but the color infrared film showed disease symptoms 1-3 days before they became evident on the ground. Ground reflection caused some error after defoliation occurred. Disease of beans was also easily identified by Philpotts and Wallen (1969) using infrared color and black and white film.

Disease has long been a serious problem for the citrus trees of Florida. Ground surveys were very costly and time consuming. Norman and Fritz (1965) developed a system of detecting disease and decline by the use of helicopter and color infrared film. Healthy trees appear various shades of blue. This method is now being used by the state.

Disease and insect damage destroy a large amount of timber and shade tree species. For this reason, a great deal of research is underway to study the value of remote sensing to the forester. Meyer and French (1967) used color infrared film and a fixed winged aircraft to detect the spread of Dutch Elm disease into Minnesota. They found that stero-paris were far superior to single photos. Infrared-absorbing surfaces such as pavement seen through openings in the tree crowns, were often interpreted as dead or diseased portions of the tree - a feature which stereoscopic examination would normally detect. Tree species identification and radial displacement was also improved. Detection of the disease was possible for 59 of 73 tagged trees. However, the 14 trees missed were adjacent to identified trees. Wert (1969) evaluated the effects of air pollution on tree leaves in southern California. He found the greatest variation in spectral response occurred in the visible absorption range. Conventional film should be useful in detecting this pollution damage.

Thermal infrared scanners are also being used to detect diseased trees. Neubert (1969) used a scanner and a TV camera to get pictures and temperatures of douglas fir affected with a root disease. Temperature differences at 8-14 microns were highly significant in the early morning even if disease symptoms were not always visible in the crowns of trees. Diseased trees are not able to accumulate water for transpiration even over night, while healthy trees accumulate water. Thus, in the early morning healthy trees transpire a large amount of water and leaves remain cool, but the diseased trees have a low rate of transpiration and leaves become warm. Differences in temperature were 3-5°C between healthy and diseased trees. Differences were reduced during the day as healthy trees came under moisture stress. Rhode and Olson (1970) used a 8-14 micrometer scanner to study the effect of moisture stress on hardwood tree species. Stands of Balsam poplar and oaks were partly girdled with a chain saw. Trees girdled in the oak stand showed higher temperatures a few days after girdling. Temperature variations could not be detected during night hours, but could be detected during day time. Conventional and infrared films also showed the moisture stress. The Balsam poplar failed to show a moisture stress, probably due to improper girdling.

Wallace (1973) reported that remote sensing could be used for the detection of overland flow of pollutants as runoff from feedlots. The most promising method of detection seems to be the comparison of relative soil moisture content and vegetative differences.

Infrared thermal recorders are also being used to measure thermal pollution of water (Van Lopik et al. 1968). Industrial thermal pollution was detected at 10-14°C higher temperatures than those of a Texas bay. Temperature variations of only 1.5°C were also measured using the 8-14 micron range. This range appears the most useful because (a) bodies at the temperature of the earth's surface produce maximum emission at these wavelengths, and (b) atmospheric absorption is at a minimum.

Crop and Tree Species Identification

Identification of crop and tree species from the air could be very useful for certain farm programs, inventories, and other economical uses. Research programs at the University of Michigan and Purdue have attempted to identify field crops by the use of multispectral photography and infrared recording. Signatures from known crop species are given a notation which is then placed on unknown fields with similar signatures by a computer. Accuracy of prediction depends on condition of crop (LARS 1968). Identification of crop species was poor in fields where plants, such as corn, were young or short, and percent ground cover was low. Philpott and Wallen (1969) used infrared color, visible color, and crop characteristics to identify crop species Brooner and Simonett (1971) examined the feasibility of discriminating agricultural crop types with color infrared photography taken in late July in northeastern Kansas. Their analysis of the three color emulsions of the infrared film, as measured by the densitometer, generally did not enable discrimination of the crop types studied in late July.

Wide variations in needle and leaf reflections occur between tree species (Fritz 1967). True fir (Abies spp.) reflects only 20% of the radiation at 720-900 millimicrons while birch (Betula spp.) reflects 50-60%. Lauer (1969) used the same reflection range (color infrared film) to identify giant sequoia. Identification of 90% of all mature and overmature trees was possible, but accuracy dropped sharply due to similar tones for ponderosa pine and incense cedar.

Identification of timber types was attempted by the TVA (Northrop and Johnson 1970). Multispectral photography of forested areas was taken during time of peak fall coloration and early spring. Topography positions, aspect, and slope was classified for the flight area. Tree species expected to occur on each topography were then listed. Interpreters first classified the stand position and then used the stand table to find possible tree species present. Color and tonal values were also recorded for each topography position. Tone or color value was used to determine final forest type. Accuracy was only 36% for SAF classification. Grouping some SAF classes together (e.g. oak species) gave an accuracy of 61%. A large scale of 1:12,000 gave no better results than 1:20,000.

Rohde and Olson (1972) found they could get a recognition accuracy of 85 percent with the use of computer recognition of forest tree species using multispectral sensing. They were able to achieve successful separation of coniferous and broadleaved trees. Specific recognition and separation of sugar maple, black walnut, black locust, red oak, and white oak were also successful. Discrimination among conifers was not so successful as for broadleaved species, but spruce were consistently separated from pine.

Soil Identification

Areas which have received attention include (1) reflectance of soil materials and conditions and characteristics affecting their reflectance, (2) environmental factors (or natural causes) influencing the quality of the aerial photographs used in soil survey, and (3) films (especially black and white vs. natural color) and filter combinations that improve the quality of the photos, including spectral band regions.

One of the first attempts to identify soil variations by remote sensing was made at the University of Purdue (Hoffer 1967). Flights were made over two varying soil types (one with a dark silty clay A horizon and the other a light colored silt loam) employing both multispectral photography and thermal infrared recording. The same responses were found in the reflective infrared, but the dark colored soil absorbs more incoming radiation; and, therefore, became relatively more emissive in the thermal infrared. However, Myers and Heilman (1969) found that lighter textured soils had higher temperatures (62°C) at night than the heavier textured soils (52°C). Night hours gave the greatest variations in soil temperatures. Dry fields of the same soil type varied from 45-51°C while wet soils varied from only 40-42°C.

An attempt to identify soils and drainage patterns by multispectral photography was made by Kuhl (1970). Five sites with several soil drainage classes were chosen and multispectral photographs were taken of them. Stereo-pairs were used to identify slope and all similar tones were delineated on clear plastic. A soils base map was then made using a scale of 8" to a mile. Accuracy in estimating drainage classes was 36-49% depending on site.

Estimation of USDA slope classes was somewhat higher. No significant difference in film type was found in determining drainage or slope. Soil erosion and texture could not be determined.

Cihlar and Protz (1972) identified six transects crossing 16 soil mapping units in the field and on color aerial negatives. Microdensitometric measurements of small increments along the transects on the negatives were analyzed using discriminant analysis with respect to effects of training sets, ground resolution element sizes and type of film material. The overall accuracy of identification was 39.7% for ideal training sets and decreased gradually if the sets were modified to suit practical requirements. Different ground resolution elements did not substantially alter the accuracy. They concluded that color aerial films are capable of recording information which can be used to separate soil mapping units.

The fact that most of the remote sensing instruments that have been used sense the reflected electromagnetic energy has made the nature of the reflectance of soil materials an inescapable topic of research. Any given soil material would certainly have different reflectivity under different conditions (e.g. moisture conditions) and for different regions of the electromagnetic spectrum.

The factors influencing the reflectance of soil materials are recognized as (Gates, 1970): coloration, texture, moisture content, roughness, mineral and chemical composition, angle of illumination, and degree of shadowing by other objects between the soils and the "line of vision" of the sensor. Surface color of most agricultural lands is normally a reflection of organic matter content, except where it is modified by other constituents such as iron oxide or salt accumulation.

There have been attempts to evaluate how much the different factors affect the final aerial photograph and thus the accuracy of soil delineations, and ways of minimizing these effects and improving the qualtiy of interpretability of the aerial photographs. Some of the published literature that have addressed themselves to the different aspects of soil material reflectivity are enumerated below.

Cipra et al. (1971) made in situ measurements of soil reflectance in the 430 to 730 nm wavelength band under natural conditions with a field spectrophotometer. They found a higher total percent reflectance for a somewhat poorly drained Alfisol (Fincastle) than a very poorly drained Mollisol (Chalmers), a higher total percent reflectance for soils in dry condition than for the same soils in wet condition, and similarities in total percent reflectance between a very poorly drained Mollisol (Chalmers) and a very poorly drained Histosol (Carlisle).

Hoffer (1972) has shown that where different soil types are involved it is not always easy to separate dry from wet soil moisture conditions. LARS (1971) have reported studies on effects of moisture content on soil reflectance and found a very large decrease in total percent reflectance with increase in moisture content. The shape of spectral curve remains the same for clay soils but a marked change occurred in the shape of the spectral curve for sandy soils.

Hoffer and Johannsen (1969) using more than 250 soil samples, 10 different soil textures, 4 drainage profiles, and 3 major soil horizons, found the same results at LARS. The water absorption bands are at approximately 1.45 and 1.95μ and become pronounced for sandy soils with a moisture content of over 4%. They suggested that bound water might be exerting an influence on reflectance of bentonite and muscovite at 1% moisture content.

These authors further point out that because soil tends to dry on the surface forming a thin crust (which can develop within a few hours after rainfall), the reflective measurements using remote sensing devices could show that the soil appears to be dry while the profile may actually be wet, and that this may indicate a possible limitation in the utility of reflective data alone.

Condit (1970) working in the range of 320 to 1,000 nm used 160 soil samples from 36 states. An examination of the 160 sets of curves indicated that they could be classified with respect to curve shape into three general types. He concluded that the spectral reflectance of a wide variety of soils can be predicted with sufficient accuracy by measurements made in only five wavelengths.

Mathews et al. (1973 a) found clay type and the amount of organic matter, free iron oxides, and silt influence the intensity of energy reflected by soils in the range of 0.5 to 2.6µm. High organic matter content and free iron oxides reduce reflectance intensity in the 0.5 to 1.2µm range. Clay type influenced curve shape and intensity over the range 0.5 to 2.6µm.

Coulson (1966) found by measurements of reflecting and polarizing properties of soils, sands, and vegetation in visible and near IR regions that the reflectance of mineral surfaces increased with increasing wavelength and increasing angle of incidence.

Bowers and Hanks (1965) evaluated the influences of moisture content, organic matter, and particle size on the reflection of radiant energy from soils in the 400 to 1,000 nm spectral range. At all wavelengths on all samples reflectance decreased and absorbance increased as moisture content increased. The oxidation of soil organic matter increased the reflectance from all samples measured. With kaolinite and bentonite clays, reflectance increased exponentially as particle size decreased. The magnitude of reflectance change was very similar with both clays.

Other factors which influence the quality of the aerial photos used in soil surveys can be regarded as natural causes. These include illumination, haze, angle of the sun, scattering of the light, and other anomalies caused by climate which, in photographs, are reflected in photo grey tones, erosional features, and vegetation. A discussion of some of these factors can be found in Frost (1953) and Heller (1970).

Pomerening and Cline (1953) measured the effects of complexity of landscape on the accuracy of soil maps prepared by the use of aerial photo interpretation. They found increasing complexity of the terrain reduced the accuracy of aerial photo interpretation.

A questionnaire by Swanson (1954) found the preferred time for taking photos coincided with the period of the year when soil cover is at a minimum, preferred photos taken when the shadow effects were smallest, and preferred photos taken when soils are at intermediate moisture contents.

The USDA recommends the panchromatic film for routine soil survey work because of its "all-round adaptability and low cost", (USDA-SCS, 1966). Hence, this film has been used almost exclusively in this work. However, many researchers have evaluated the potentials of other films, especially the natural color negative producing film.

It was realized early that in addition to the tonal variation, which in panchromatic films is the only parameter usable for delineation, the color available in the natural color films might produce an added advantage and thus increase the interpretability of aerial photos. Recent years have seen great progress in this direction.

Shallock (1968) noted that metric qualities of color photography compared favorably with black and white photography.

Parry et al. (1969) noted that although it seemed unlikely that specific color signatures could be obtained from aerial photos at the soil series level, it was apparent that considerable advantage existed in using color film in attempting to identify and plot soil boundaries, differentiate soil type within a series, and distinguish changes within a soil type resulting from differences in moisture or organic matter contents.

Anson (1970) found color aerial photographs to yield a more accurate and rapid means of identifying culture and land use, allow greater soils differentiation, and give the interpreter more confidence in his decisions.

Simakova (1959) found photos from two layer spectral color film were more accurate in interpreting soil types than both black and white and color infrared photos.

Rib (1967) reported on a multisensor study to determine an optimum combination of sensors for analyzing soils. For interpretation and detailed mapping of soils, natural color aerial photography was the most useful single film type. Infrared color photography was not as suitable for soil mapping as the natural color aerial photography. The natural color appearance made it possible to determine whether the tones were due to intrinsic soil color, moisture, vegetation, or cultural features.

Dominquez (1960) concluded that boundaries between soil types could be delineated more accurately and more quickly on color than on black and white aerial photos.

Maruyasu and Nishio (1961-1962) found that except for the "complexities of the process of photographic treatment, color aerial photos are superior to monochromatic photos in all respects". The experimental studies were made in 1956 and 1957.

Unlike the early days when soil survey reports were considered basically as being useful for the farmer, there has been a great demand for these reports from other land users, and this user diversification has resulted in the realization that quicker and more accurate methods of soil survey have to be found. Although NASA's ERTS-1 project was intended to serve only as an experimental system, the vast amount of data that the ERTS-1 satellite and its MSC support aircraft are providing have come in very handy in the increased demand for land use information. This project has also added a new dimension to the field of remote sensing. Between March 5 and 9, 1973, a "Symposium on Significant Results Obtained from the Earth Resources Technology Satellite 1" was held by the Goddard Space Center in New Carolltown, Maryland. The presentations in this symposium are published in three volumes. Some of the presentations regarding the field of soil survey are summarized below.

Anderson et al. (1973) found that geologic analysis demonstrates that most of the major rock units and geomorphic boundaries shown on the available geologic maps could also be identified on the ERTS data. All of the previously mapped granitic intrusive rocks in the area were identifiable on the images; however, a radical drainage pattern about 7 km in diameter, probably indicative of a buried intrusive, was recognized for the first time on the ERTS images.

Elbersen (1973) from an interpretation of ERTS-MSS images of a Savanna area in Eastern Colombia found most of the important units of an existing 1:250,000 reconnaissance soil map could be extrapolated successfully into an unknown similar area using ERTS imagery in conjunction with sample strips of aerial photography. The resulting map showed sufficient detail to justify a publication scale of 1:500,000.

Parks and Bodenheimer (1973) were able to delineate the major soil associations in the loess region of Obion County, Tennessee, accomplished using ERTS 1 imagery with Channel 7 providing the clearest differentation. Soil differentiations were accomplished visually as well as electronically using a scanning microdensitometer.

Baumgardner et al. (1973), while mapping soils, vegetation, and water resources of Lynn County, Texas, found features which were identifiable included row crops, unimproved and improved rangelands, bare soils, hydrologic features, and gross geologic and soil features. Results suggest that these techniques may be used to identify drought and other crop stress conditions, crops damaged by hailstones, areas of active wind erosion, crop species, and soil patterns.

Lastly, but by no means least, a method of mapping soils by computer-implemented pattern recognition techniques has been under experimentation for several years now. This has been successfully employed by Parks and Bodenheimer (1973) in their investigation reported above. Kristof and Zachary (1971) have reported partial success with this method, the difficulty arising when attempts were made to "map" a soil series (or soil type) in one soil test area located at a distance of several km from the first.

Stoner and Horvath (1971) found less than 25% of soil cover by soybeans posed no problem in delineating soil patterns from computer implemented analysis of multispectral scanner data. Where distinct light and dark patterns often distinguish the members of a drainage catena, gross soil patterns can probably be delineated from MSS data unless vegetative ground cover is almost complete. Even with partial ground cover, computer-implemented spectral mapping of soils can be done with proper selection of pattern recognition algorithms.

Mathews et aL (1973b) reported computer analyses of multispectral imagery collected from aircraft shows promise for reducing preparation time and increasing the accuracy of soil survey maps. Limestone, shale, sandstone, and local colluvial soils were separated with a high degree of accuracy.

Another method of multispectral data analysis which shows potential for reducing preparation time and increasing the accuracy of soil survey maps is the density analysis (color enhancement) method. Frazee et al. (1972) has reported that a color coded image of an area of Lake Dakota Plain showed a more accurate location of soil boundaries than the existing soil map. Odenyo (1973) applied a similar method in Norman County, Minnesota, and concluded that the soil boundaries were more accurately located on the color-coded density maps than on the existing soil maps of the area. An added advantage in this method, which may prove especially useful where land use estimations are to be made, is the possibility to get an areal estimation of the separate soil delineations.

REMOTE SENSING OF VIRGINIA TRUCK AND ORNAMENTALS RESEARCH STATION

Study Area

The Virginia Truck and Ornamentals Research Station at Painter is located 30 miles southwest of the NASA-Wallops Station. The topography of the area is level to gently rolling. The research station farm is comprised of about 100 acres arranged in rectangular fields which are conducive for photographic analyses as shown in Fig. 2. There are some 25 fields on the farm which have a mean width of 220 feet and length of about 1,200 feet. The farm is bordered on three sides by wooded areas.

Soils

Soils on the research station have been evaluated and a detailed soil map previously prepared by Porter and Moody (1967) has been refined. The soil type map is given in Fig. 2. Soil descriptions are given in Appendix A.

Textural analyses of representative soil pedons at various locations on the research station are presented in Table 1. The sand content of the surface horizons ranged from about 35 to 70% while the silt content ranged from 25 to 53%, and the clay ranged from 4 to 14%.

Textural analyses of soil profiles from the representative soils on the research station are presented in Table 2. These data confirm previous field examinations which indicated a sharp decrease in silt and clay content at depths below 50 inches, accompained by an increase in sand content. Maximum clay contents ranged to 35% in the B horizons with average values of approximately 30%. Maximum silt contents occurred in the upper part of the soil profiles and ranged to 35%. Generally, at depths below 50 inches a very sandy layer occurs and it extends to depths of 90 inches and greater.

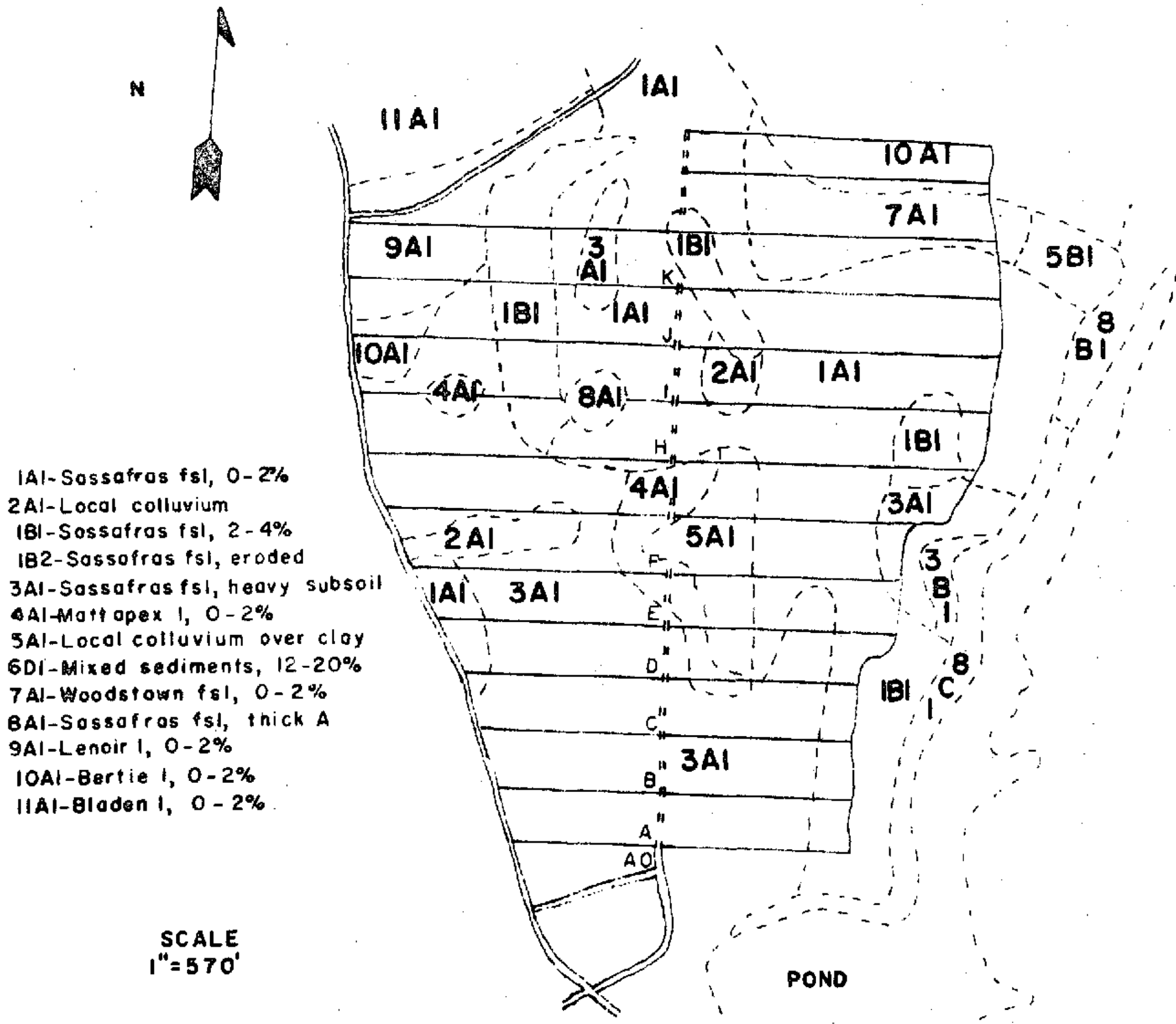

Fig. 2. General field layout and soil type map of the Virginia Truck and Ornamentals Research Station, Painter, Virginia.

Table 1. Textural analyses* of representative soil pedons at various locations on the Virginia Truck and Ornamentals Research Station, Painter, Virginia.

Field #	Horizon	Depth (in.)	VC 2-1 mm	C 1-0.5 mm	M .5-0.25 mm	F .25-0.1 mm	VF .1-0.05 mm	Total Sand Percent	Silt .05-.002 mm	Clay <.002 mm
I North	Ap	0-6	1.8	12.1	35.8	17.7	1.0	68.4	27.0	4.6
I South	Ap	0-6	1.6	12.8	33.9	19.3	0.9	68.5	25.3	6.2
I Central	Ap	0-6	2.1	12.8	33.6	19.1	0.8	68.4	26.7	4.9
H Central	Ap	0-5	3.0	11.2	12.2	19.4	1.9	47.7	43.9	8.4
H Central	B22t	20-34	4.6	13.7	9.8	9.3	1.2	38.6	36.9	24.5
G' High Pt.	B22	21-35	2.2	14.9	23.1	14.8	0.6	55.6	25.4	19.0
G' High Pt.	Ap	0-7	1.4	9.1	14.9	11.9	1.0	38.3	53.2	8.5
G' High Pt.	A2	7-18	1.4	7.7	12.9	12.5	1.1	35.6	50.2	14.2
G' High Pt.	B22t	18-34	1.9	9.4	14.9	16.5	1.1	43.8	31.1	25.1
G' High Pt.	B3	34-43	1.8	9.8	16.1	19.6	1.3	48.6	26.4	25.0
G' High Pt.	C	43+	13.0	31.9	23.2	12.0	0.7	80.8	6.2	13.0

*Particle size distribution via Pipette Method of Day (1965).

Table 2. Textural analyses of representative soil profiles on the Virginia Truck and Ornamentals Research Station, Painter, Virginia.

Soil	Horizon	Depth (in.)	Sand (2-.05mm)	Silt (.05-.002mm)	Clay (<.002mm)
Matapeake fsl	Ap	0-6	60.8	28.0	11.2
	A2	6-12	48.4	30.2	21.4
	B21t	12-24	46.4	26.0	27.6
	B22t	24-40	67.0	10.2	22.8
	IIC1	40-56	78.8	6.6	14.6
	IIC2	56-60	81.0	6.4	12.6
Sassafras fsl	Ap	0-8	75.0	16.4	8.6
	A2	8-13	66.2	20.2	13.6
	B2t	13-25	63.0	15.4	21.6
	B3t	25-31	83.4	4.0	10.6
	IIC1	31-40	92.8	1.2	6.0
	IIC2	40-60	94.0	1.2	4.6
Bertie 1	Ap	0-9	47.8	35.4	16.8
	B21t	9-13	28.0	35.0	37.0
	B22t	13-26	40.1	25.3	34.6
	B23t	26-37	58.4	10.0	31.6
	B3	37-41	81.8	4.0	14.2
Mattapex 1	Ap	0-8	39.8	35.0	25.2
	B1	8-14	39.8	35.6	24.6
	B21t	14-19	37.6	27.4	35.0
	B22t	19-27	47.8	21.6	30.6
	B23t	27-36	65.0	10.4	24.8
	IIC	36-52	83.2	0.2	16.6

Mineralogy of the typical soils occurring on the research station was determined by microscopic examination and X-ray diffraction analyses. Quartz was the dominant mineral component of the sand fraction comprising 80-95% of the total fraction. Lesser amounts of ilmenite and ferruginous opaque minerals were detected, usually in the fine sand and very fine sand fractions. The coarser sand fractions were dominantly quartz. The silt fractions were also dominated by quartz with lesser amounts of kaolinite, inter-layer vermiculite, and iron oxides. The clay fraction was comprised of kaolinite, inter-layer vermiculite, and quartz.

Fig. 3 illustrates an X-ray diffraction pattern of the clay fraction of a Sassafras Ap (surface) horizon. This pattern was similar to other patterns obtained for the clay fractions of representative soils on the research station. The reflection peak at 7.2A (Fig. 3) is characteristic of kaolinite, while the peak at 14.2A is attributed to inter-layer vermiculite, and the peak at 3.34A is characteristic of quartz. The X-ray reflections at 4.69 and 3.57A are second and third order kaolinite and inter-layer vermiculite.

The mineralogical composition of the surface soil horizons on the research station consists dominantly of quartz, kaolinite, inter-layer vermiculite, and iron oxides. In the fundamental infrared spectrum, most of the diagnostic absorption or reflection frequencies occur beyond the sensitivity range of the infrared film used in this study. The infrared analyses of common soil minerals is most diagnostic in the fundamental infrared band from 2.5 to 20 microns, and the far infrared range of 20-200 microns according to Farmer and Russell (1967). Soil minerals have characteristic vibration bands near 2.75 microns (HOH vibration) and 2.95 microns (free HOH). Similar bands near 6.2 microns are characteristic of

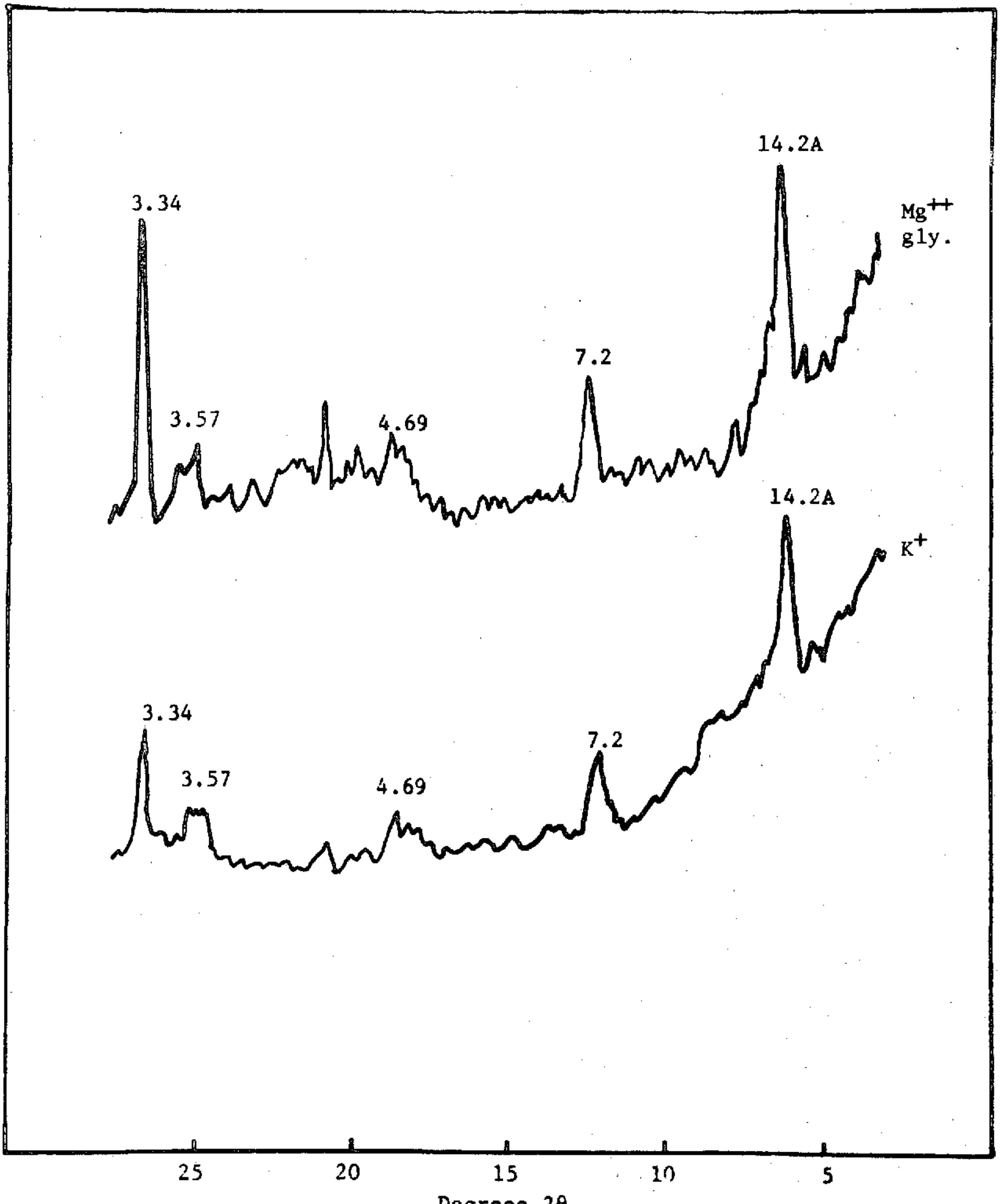

Fig. 3. X-ray diffraction patterns of the clay fraction (<2μ) of a typical Sassafras Ap horizon, Mg^{++} saturated-glycerol solvated, and K^{+} saturated.

HOH bending while broad bands near 8.8 to 10.3 microns are attributed to SiO vibrations.

Because of the limitations of the range of the infrared film in this study, the ultraviolet and visible part of the spectrum should produce the most information on the bare surface soils. However, multispectral and thermal sensing offers considerable promise, and the physical and mineralogical data should be quite useful when this coverage can be obtained.

Wooded Areas

A forest type map has been prepared for the wooded area surrounding the research station indicating tree species, stand density, tree heights, understory vegetation, and visible insect and/or disease damage. The forest type map is presented in Fig. 4. A supplement to the field boundaries and forest type map is given in Appendix A.

Monitoring System and Equipment

It was evident in the initial stages of the project that a datum needed to be established for the environmental variables at the research site. An environmental monitoring system was established at the research station to continuously measure soil temperature, air temperature (wet and dry bulb), wind speed and direction, and solar radiation. A Matrix Inc. Sol-A-Meter type integrating pyrometer (Fig. 5) continuously measures solar radiation and records the data on a small strip chart recorder. The use of Atkins soil temperature probes (Fig. 6) with an accuracy of ±0.2°F permits soil temperature measurements at regular intervals at remote locations on the research site and at various soil depths. A Weather Measure instrument is used to measure wind speed direction. The soil temperature, relative humidities, and wind speed and direction are continuously recorded on a

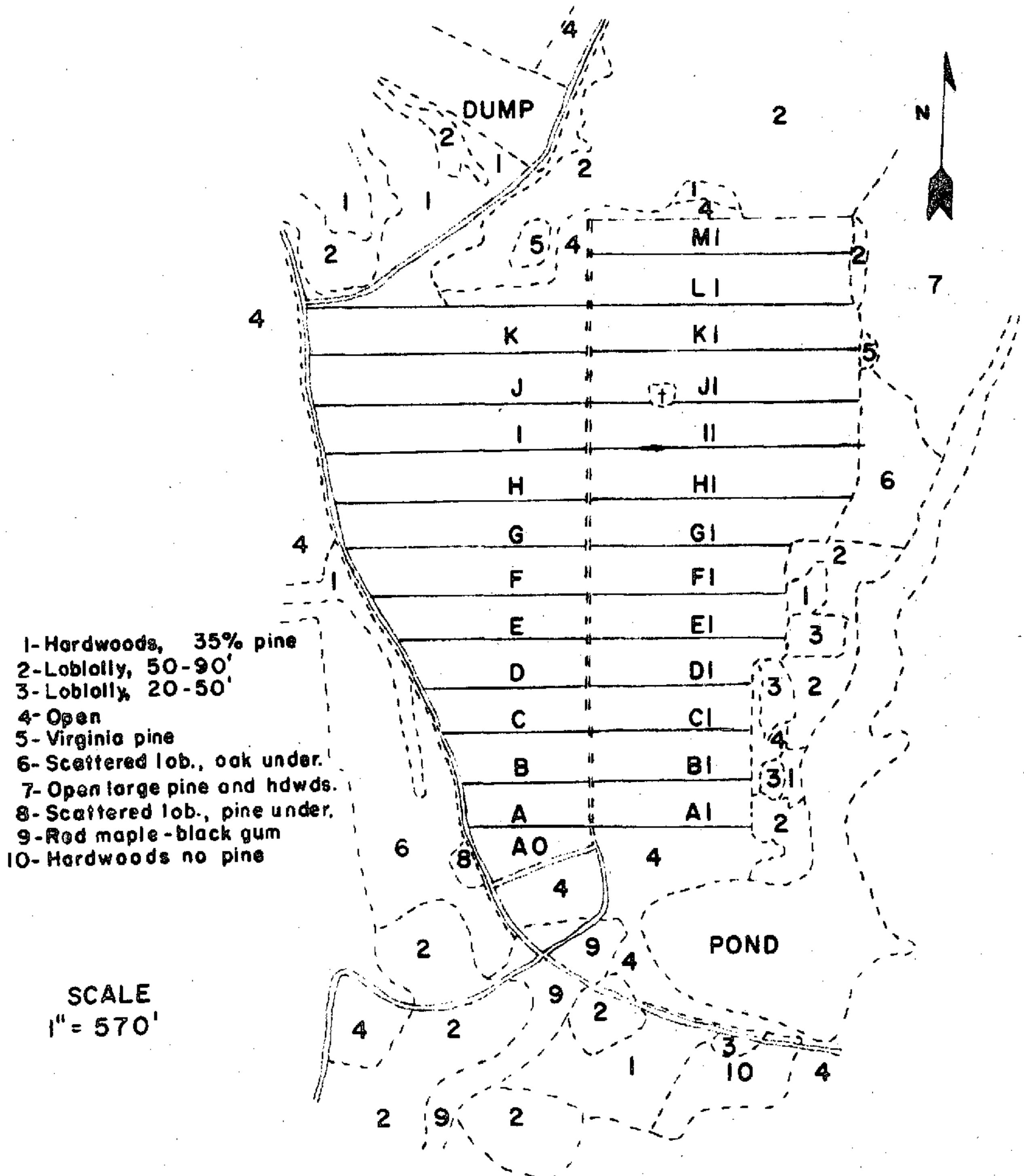

Fig. 4. Field boundaries and forest type map of the Virginia Truck and Ornamentals Research Station, Painter, Virginia.

Fig. 5. View of the Matrix Inc. Sol-A-Meter type integrating pyronometer (top of post) used to measure solar radiation and the hygrometer used to measure wet and dry bulb temperatures (hanging under pyronometer) at the environmental monitoring station on the Virginia Truck and Ornamentals Research Station, Painter, Virginia.

Fig. 6. View of a Atkins soil probe used to measure soil temperature at the environmental monitoring station on the Virginia Truck and Ornamentals Research Station, Painter, Virginia.

Bendix 24-channel recorder. The equipment is housed in an instrument building located near the center of the farm (Fig. 7). The building has a power supply and self-contained temperature control system to protect the instrumentation. The instrumentation systems are calibrated on a regular schedule by NASA technicians to ensure accuracy.

Presently, the strip charts containing the environmental data are removed each month and forwarded to the Department of Agronomy at VPI & SU for conversion to standard format, recording, and analyses. The instruments permit visual read-out of the data during actual flights. However, transposing the multitude of data from charts to digital format requires considerable time and expenditure of man power. A feasibility study has been conducted to evaluate automatic data conversion systems for the station. Installation of an automatic system is anticipated in the near future.

This information provides a datum of the environmental variables at the research site as well as area conditions. A knowledge of these variables during remote sensing overflights permits relationships between environmental factors and image quality to be established. These data also are important to the establishment of spectral signatures of various soil and crop conditions under different environmental conditions.

The environmental monitoring station is unique since there are no facilities within the area monitoring these variables. Availability of this data to the agricultural sector of the region appears to be an important "spin off" of this project.

Flights Flown and Photographic Analysis

Between August 12, 1969, and September 6, 1973, a total of 30 flights have been flown over the Virginia Truck and Ornamentals Research Station at

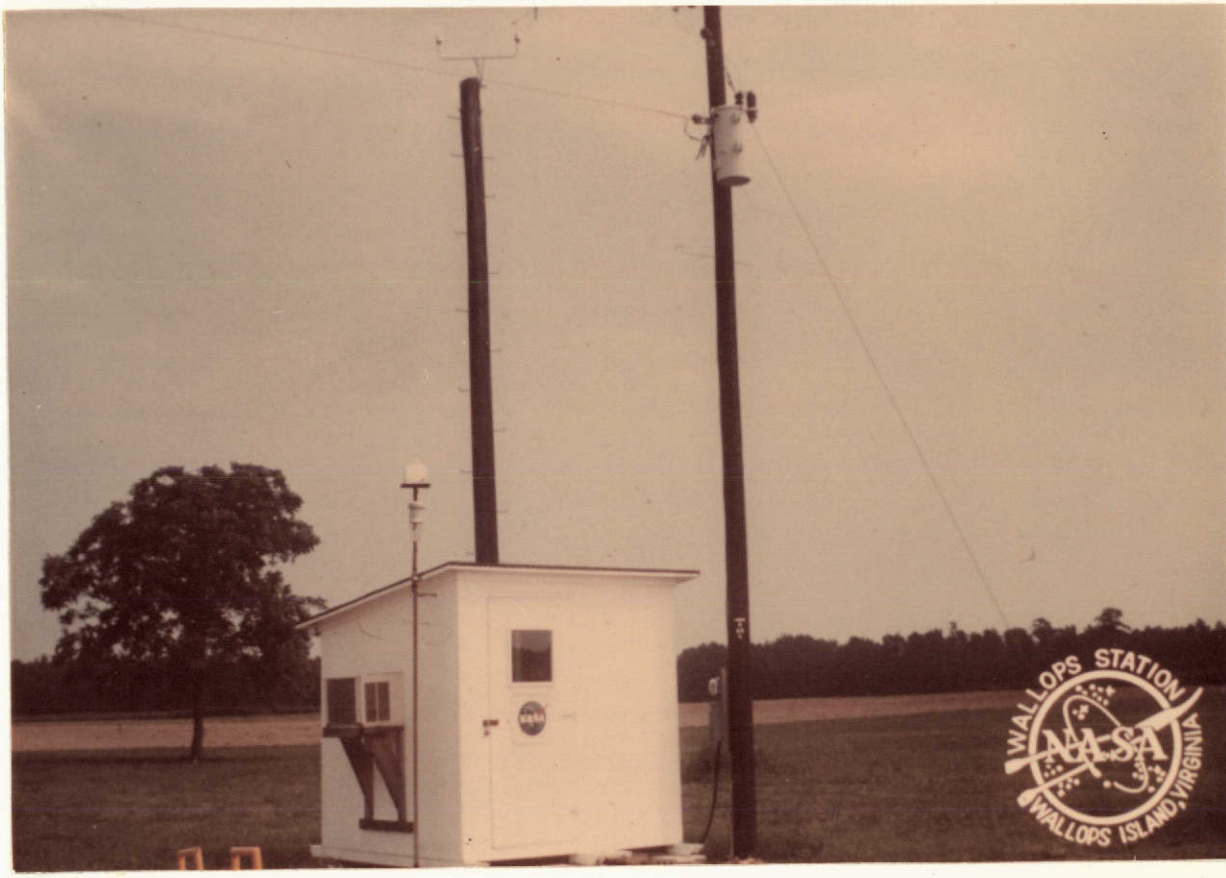

Fig. 7. View of the environmental monitoring station at the Virginia Truck and Ornamentals Research Station, Painter, Virginia. The weather measure instrument for measuring wind speed and direction is located at the top of the pole directly above the building. The Matrix Inc. Sol-A-Meter and hygrometer are also visible.

Painter, Virginia. A review of the flights flown, dates, and imagery data collected is given in Table 3. Flights from 1969 through 1972 have been analyzed by various methods and correlated with ground truth data. Imagery data collected in 1973 is presently being evaluated and will be correlated with ground truth data.

An aerial view of the research station is given in Fig. 8. Both color SO-397 and color IR 2443 views are presented. Notice how the wetter areas (dark color) appear more pronounced on the color IR 2443 photograph.

Early in the program it became apparent that two variables which affect the quality of the imagery data for use in remote sensing had to be eliminated or minimized. The variables are color shift and vignetti effects.

The effects of soil moisture and organic matter on the reflection of Sassafras soils at 650 and 900 millimicrons were analyzed. The use of scanner data for the discrimination of forest types has also been studied.

Vignette and Color Shift

In the past decade several researchers have used tonal and color variations of aerial photographs to detect important agricultural conditions (Colwell 1968, Molineux 1965, Scherz et al. 1969, USDA 1972, and Northrop and Johnson 1970). An example of the specific use of photographic techniques is the assessment of crops and tree diseases (Houston 1972, and Philpotts and Wallen 1969). Several other uses are well documented in the literature.

Initial analysis of photographic images were made by two techniques. Visible analysis was and still is the most common method utilized, while the use of a Munsell color book system is also widely used. Both of these techniques employ human ability to distinguish various color and tonal variations, thus limiting their reliability.

Table 3. Flights flown over the Virginia Truck and Ornamentals Research Station and imagery data collected.

Date	Imagery	Remarks
08/12/69	B/W IR, DX, Color IR, Ektachrome 8442	Helo
02/19/70	B/W IR, DX, Color IR, MS Color	Helo
11/05/70	--	Univ. of Mich. C47
12/15/70	--	Helo
03/05/71	B/W IR, Color IR	Helo
04/30/71	B/W IR, Color IR	Helo
05/17/71	B/W IR	Helo
06/01/71	B/W IR, Color IR	Helo
06/14/71	B/W IR, Color IR	Houston A/C
06/28/71	B/W IR, Color IR	Helo
07/14/71	B/W IR, Color IR	Helo
07/30/71	B/W IR, Color IR	Helo
08/20/71	B/W IR, Color IR	Helo
09/15/71	Color, Color IR	Helo
11/18/71	Color, Color IR	Helo
04/05/72	Color IR	C-54
04/24/72	Color, Color IR	C-54
05/12/72	Color IR	Univ. of Mich. A/C
06/01/72	Color, Color IR	C-54
06/12/72	Color, Color IR	C-54
06/26/72	Color, Color IR	C-54
07/10/72	Color, Color IR	C-54
08/21/72	Color, Color IR	C-54
09/11/72	Color, Color IR	C-54
10/26/72	Color, Color IR	C-54
12/18/72	Color, Color IR	C-54
05/31/73	Color, Color IR	C-54
07/27/73	Color, Color IR	C-54
09/06/73	Color, Color IR	C-54

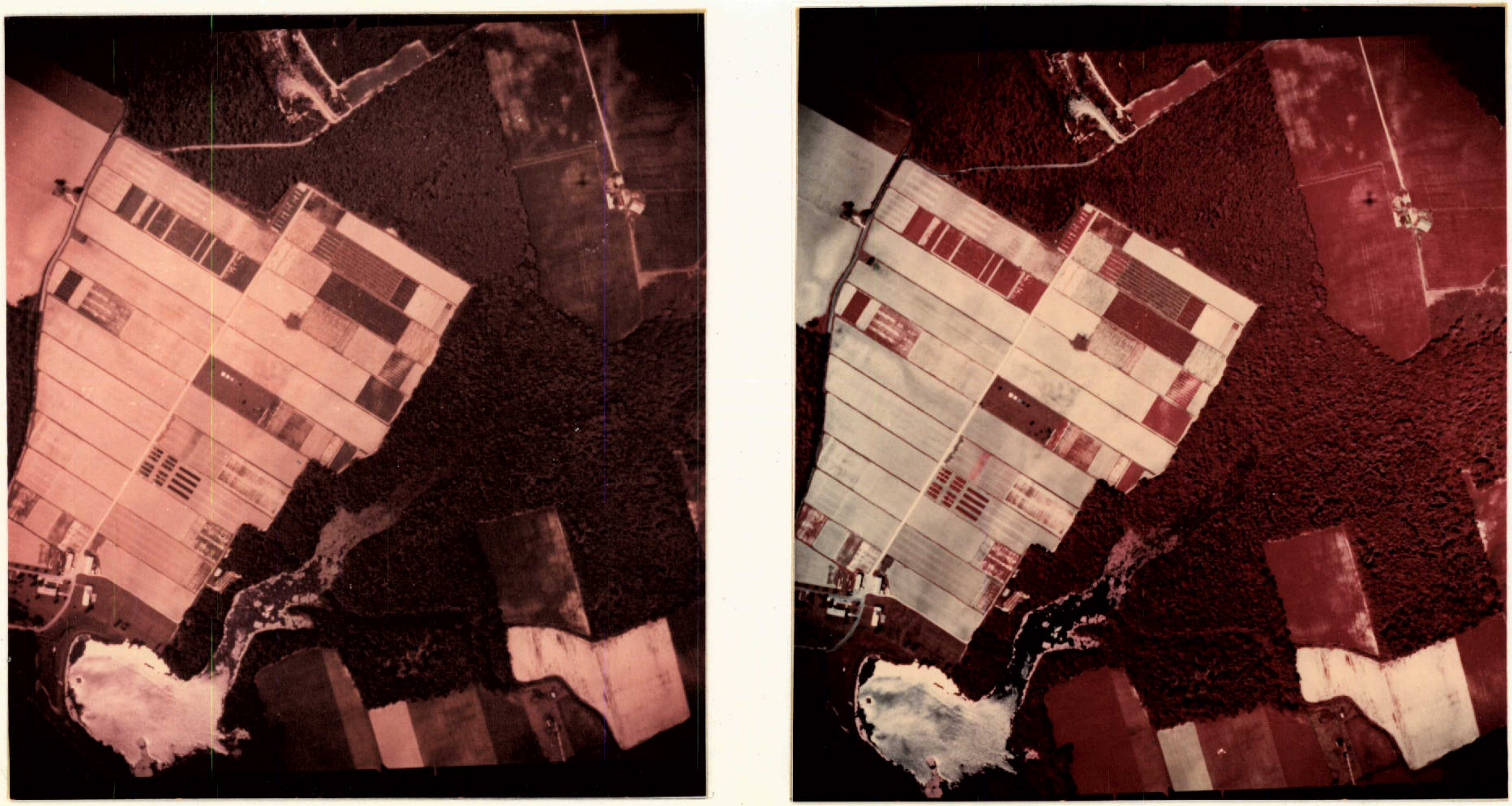

Fig. 8. Aerial view of the Virginia Truck and Ornamentals Research Station, Painter, Virginia. The left photo is color SO-397 and the right photo is color IR 2443. The photos were taken September 6, 1973.

Several types of density instruments are also being used to analyze tonal variations between conditions on a photograph. Spot type instruments measuring a small specific area and the more complex isodensitometers measuring entire photographs in combination with density wedges are commonly used. Both types of instruments have the disadvantages of high cost for good accuracy and lengthy time of processing.

The most recent development in analyzing photographs involves the use of scanning densitometers (three types) in combination with computer data handling (Anuta 1970, Fu et al. 1969, and Hoffer et al. 1972). Most instruments divide the density scale into 2^n levels; 256 levels is not uncommon. The results can then be displayed on a panel or as a computer line-printer gray scale printout. The accuracy of this type of analysis is not limited by instrument or techniques but by the quality of the photographs. "This is caused by difficulities in calibrating the film to account for variations in exposure and development and in controlling illumination across the entire frame" (Hoffer et al. 1972).

It now appears the analysis of photographic images has advanced past the quality of the photographs being analyzed. Because of this, a study was initiated in an attempt to make improvements in photographic quality by reducing the influence of the vignette and color shift.

Beginning in the spring of 1971 biweekly flights were made of the Virginia Truck and Ornamentals Research Station at Painter, Virginia, utilizing either a Bell #104 helicopter or a C-54 aircraft equipped with duplicate Kodak color aerial infrared Ektachrome #2443 film with a Wratten #25A filter and color #SO-397 film with a #HF-4 filter. Initial objectives of these flights at altitudes from 500 to 10,000 feet were to evaluate these two types of film as related to the detection of crop diseases, crop identification, and other agricultural variables. On the day of each flight, all relevant ground truth data was collected on each of 25 rectangular fields.

The resulting 9-1/2" square positive transparencies of 12 flights made in 1971 were analyzed by two methods. First, all fields and sections of fields with different treatments were color coded with a complete Munsell book of color. Later a microdensitometer (Optronics International, Inc. Model P-1700) was used to analyze selected photographs.

By late 1971 an anti-vignette filter had been added to the cameras to correct for vignette encountered in the initial analysis of the 1971 flights. Vignette, as used in this paper, means the over-development of the central portion and an underdevelopment of the outer portion of a photograph caused by an unequal distribution of light across the frame.

In April, 1972, a test flight was made to determine possible causes for color shift, another photographic problem recognized after elimination of the vignetti problem in late 1971 (color shift is defined as the shift in color and tone of a selected area on two adjacent photographs on the same roll of film). Flights were made at one half hour intervals from 0900-1300 (e.s.t.) covering the farm. All lines were flown parallel to the central farm road and at an altitude of 1,000 feet. Besides the usual ground truth data, additional data taken at each flight time included solar radiation in Langleys, solar altitude, haze, cloud conditions, and other important climatic variables. Selected photographs of this flight were also analyzed by both the Munsell and microdensitometer types of analysis.

Because of the results of the April, 1972, test flight, it was recommended that the remaining eight flights in 1972 be flown perpendicular to the sun and not into the sun as previously recommended. The resulting color IR and color photographs of these flights were also analyzed by both the Munsell and microdensitometer types of analysis.

The results of the first eight flights made in 1971 showed a large amount of vignetting. Bare soil colors as measured by both the Munsell color system and microdensitometer showed striking variations in both color and tone from the center to the outer portion of a photograph. A portion of a uniform bare field located near the center of a typical color IR photograph (April 30, 1971) appears as a 5B 9/1 color, while the same field located near theouter edge of the photograph appeared as 5B 5/4. Density values measured by the microdensitometer varied from 0.03 in the center portion of the photograph to 0.30 in the outer portion, significant at the 99% level.

A rye field on the same photograph showed a color variation from 2.5R 3/8 to 5RP 5/10 due to vignette. Density values for this visibly uniform field of rye varied from an average of 0.72 in the center portion of the photograph to an average value of 2.36 at the outer portion of the photograph (using a density scale of 0.00-3.00). Similar amounts of tonal variation severely restricted the use of the remaining seven flights made in early 1971 for any density-computer type of analysis.

Fig. 9 illustrates vignette. Note how the center portion of the photograph (Color IR 2443) is very light compared to the outer edge. Fig. 10 illustrates the vignette by the use of false color images produced by an isodensitometer. With the addition of an anti-vignette filter to the cameras in late 1971, the remaining four flights showed no measurable vignette. Only small areas along the extreme outer edges and the

Fig. 9. An illustration of vignette. This photograph covers a portion of the wooded area surrounding the Virginia Truck and Ornamentals Research Station, Painter, Virginia. (Photo taken 6/28/71)

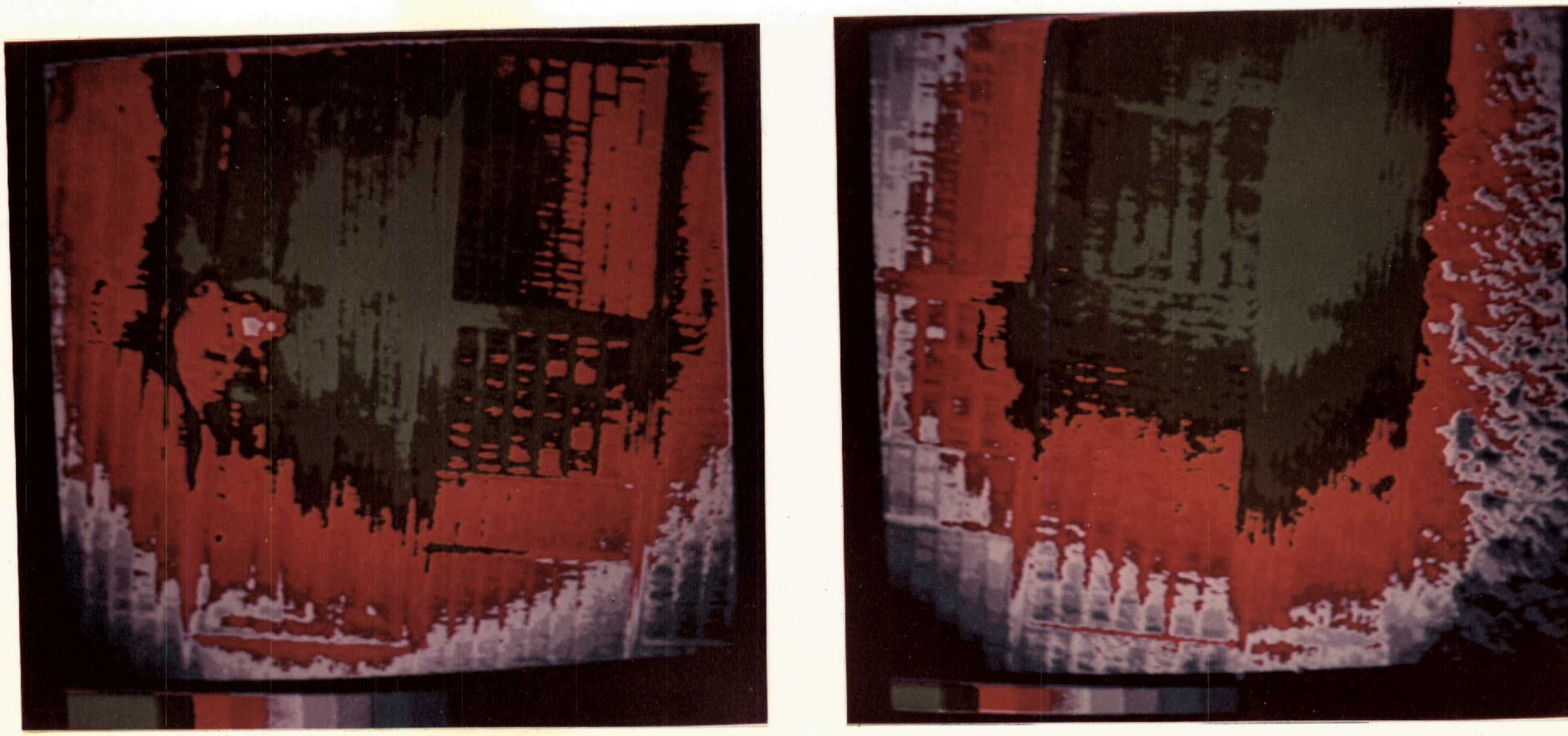

Fig. 10. An illustration of vignette by use of false color density gradients produced on an isodensitometer. The green color represent lighter areas on the original photographs and the blue colors are darker areas on the original photographs. The colors correspond to various density levels depicted in the density step tablet at the bottom of the photograph. Produced from frame 53 and 54 of the 8/20/71 flight over the Virginia Truck and Ornamentals Research Station, Painter, Virginia.

corners of the color and color IR photographs showed some underexposure. However, the problem of color shift became evident. All bare and most cropped fields appeared as different colors and tones from one photograph to another. This color shift severely limited the usefulness of the photographs for any type of image analysis because the color and tone representing a field were dependent on the photograph selected for analysis.

An example of color shift is given in Fig. 11. Notice how the fields on the right side of the center road of the research station are lighter in the photographs on the right. These photographs are successive frames on the same flight path and were taken within 3-4 seconds of each other.

The test flight made in April, 1972, gave unexpected results. The relationship of the sun's altitude, total solar radiation, and the location of the field in the photograph were thought to be the cause for the color shift; however, this was not the case.

The initial flight was made at 0900 at the same solar altitude and approximately the same solar radiation as the final flight made at 1500. Results of the 0900 flight showed a large amount of color shift while the 1500 flight showed none. Analysis of all ground truth and climatic data variations between these two flights failed to indicate any possible reason for this variation in color shift between the two flight times. However, analysis of the remaining flights indicated that the color shift became less during a period from 1200 to 1500 hours. It was then decided to determine a sun flight line azimuth for this period.

To determine the azimuth of sun to the various flight lines, it was necessary to use photographs on which the aircraft's shadow appeared. By locating the center of the photograph, the angle from the flight line to the shadow could be determined. Adding 180° to this value gives the approxi-

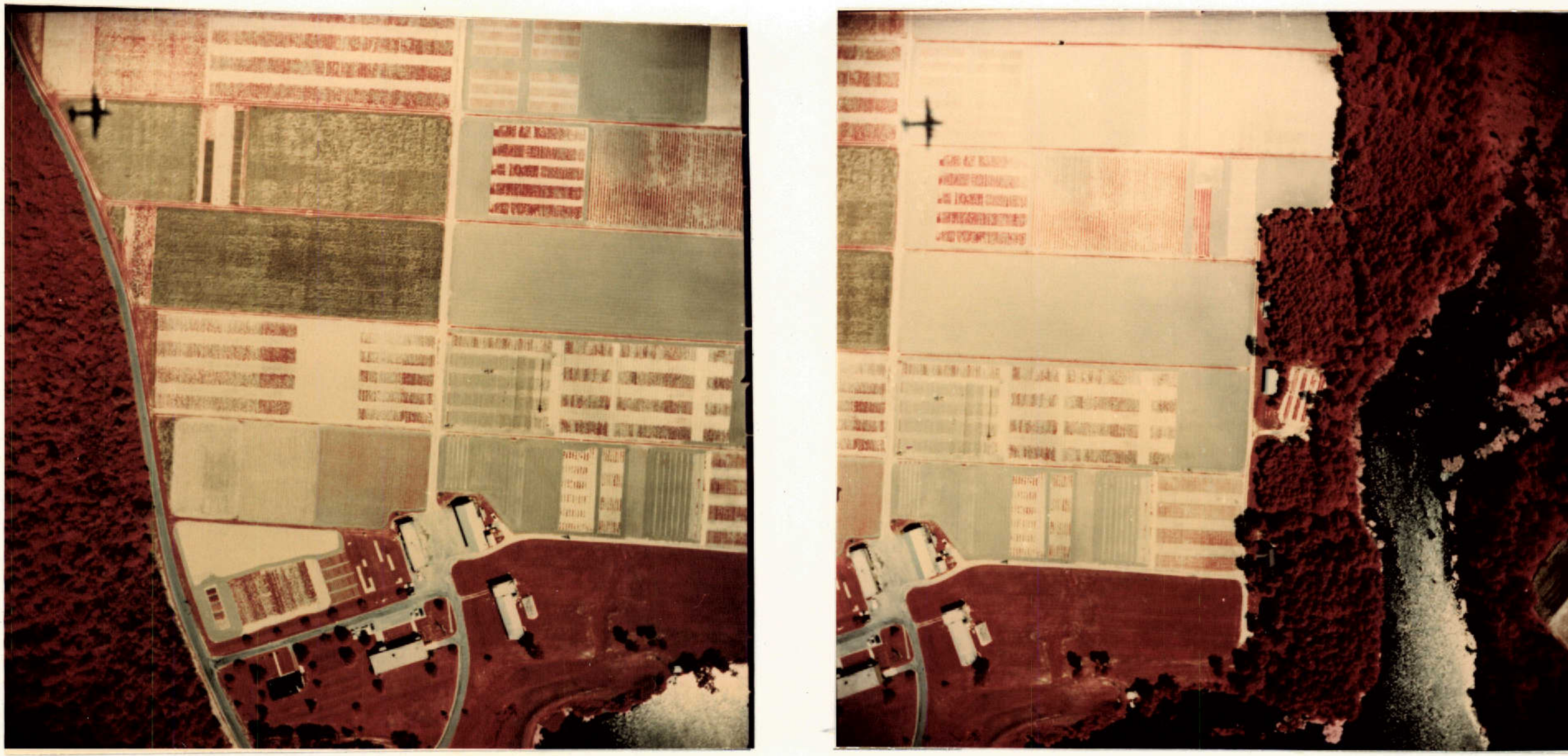

Fig. 11. An example of color shift. Note the fields on the right side of the center road of the research station are lighter in color in the photograph on the right. These photographs are frames number 24 and 25 taken on 7/10/72.

mate azimuth of the sun to the flight line. Values of 28° SE at 1200 hours, 48° SE at 1300 hours, and 68° SE at 1400 hours were calculated by actual shadow measurements. Interpolation of these results showed the sun's azimuth to be 32° NE of the flight line at 0900 hours and 88° SE at 1500 hours.

At 1200 hours a large amount of color shift occurred as evident for the same bare and rye fields on two adjacent photographs. The average density values for the bare field varied from 0.07 on the first photograph to 0.20 on the second, while the rye varied from 0.71 to 1.08 (both variations significant at the 99% level). Later flights showed less of a variation as the sun flight line azimuth approached 90°. The results of this preliminary flight indicated that color shift could be significantly reduced by planning flight lines perpendicular to the sun.

Seven flights, made later in the 1972 growing season, were used as a test to again evaluate factors influencing color shift of both color and color IR photographs. Film quality was rated from 1 (very poor) to 10 (excellent) on the basis of visible and density evaluations of color shift. These values plus all possible climatic and physical factors which might control color shift are found in Table 4. Note that a high film quality rating was found only for flights in which the sun flight line angle was between 75-90°. The only significant correlation coefficient between film quality was with the sun flight line azimuth (99% level for color IR, and 95% level for color).

Before any type of analysis of photographic images can be made, it is necessary to obtain photographs with uniform development across the frame and between various frames on the same roll of film. Uniform development across a single frame can be achieved simply by the addition of a density

Table 4. The relationship of climatic and flight variables to the magnitude of color shift found for color IR 2443 and color film SO-397.

Color Shift		Climatic and Flight Variables											
Color IR	Color	Time EST	Clouds %	Haze	Solar Rad. (Ly)	Flight Az.	Solar Alt.	% Surf. Water	Air Temp.	Soil Temp. (0-1")	% Rel. Hum.	Wind Speed (MPH)	Wind Az
1 (s)	No Film	1120	5	3	1.29	28°	68°	10	72	85	79	5	90°
10 (N)	10	1430	5	3	1.16	90°	54°	1	70	92	53	13	225°
1	1	1210	0	6	1.29	75°	74°	12	79	92	25	13	45°
9	9	1030	75	10 (S)	0.67	75°	66°	10	72	85	91	5	225°
1	3	0920	15	1 (N)	1.09	38°	51°	1	82	108	69	11	45°
1	1	0940	0	5	1.02	54°	49°	4	79	102	83	7	205°
4	8	1020	15	1	1.21	65°	47°	9	69	77	79	5	205°
10	10	1020	0	1	0.83	90°	34°	12	60	56	63	3	180°
8	10	1100	0	1	0.71	75°	27°	15	38	34	36	13	135°

(S) = Severe

(N) = None

filter to the camera system. However, obtaining rolls of film with uniformity in color and tones between frames is more difficult. Indications are that flight lines should be flown perpendicular to the sun to obtain imagery without color shift between frames. Selection of a single photographic frame for image analysis without regard to the overall quality of the roll of film in regard to color shift could result in considerable error in the analysis.

Effects of Soil Moisture and Organic Matter on the Reflection of Sassafras Soils at 650 and 900 Millimicrons

Soil scientists have used panchromatic aerial photographs as base maps for soil maps and interpretation of landscapes. These photographs often reveal major drainage areas, dominant topographical features, and may indicate drainage of a specific soil series. With the development of improved color and infrared film, new possibilities exist for better base maps that reveal more soil characteristics in greater detail. Thermal scanners are also being developed and have already shown significant variations in temperature between soils of various textures (Myers and Heliman 1969).

The evaluation of color and infrared film for identification of soil characteristics has been both optimistic and pessimistic. Gerbermann et al. (1971) found that chromas and, hence, soil drainage can be correctly separated by using the proper aerial photography. Infrared film was detected to be the most efficient in separating soils with low chromas while color film was optimum for bright colored soils. Anson (1966) (1968) reported infrared photographs were suited for dry soils (high values). Condit (1970), in a lab study of 160 different soil samples, detected at least a 20% variation in reflection between wet and dry samples of the same soil. This variation in most cases resulted in a 100% increase in reflection at a specific wavelength as a soil dried from field capacity (1/3 atmospheres tension) to permanent wilting point (15 atmospheres tension). Variations between samples possibly due to mineralogy and organic matter are also very large.

Kuhl (1970) evaluated color, black and white, and color infrared films for separating 24 soil series of eight drainage classes. Determination of drainage classes was very low for all film types (43-49%), but no consideration was made for vegetation which was present on the landscape.

The objectives of this experiment were to determine the effects of soil moisture and organic matter on the reflection of an extensive soil series at specific wavelengths. This should indicate the degree of variation in reflection and, hence, color and tone that would occur due to soil moisture and organic matter variations in the surface horizon of a specific soil series.

Methods and Materials

Fifty soil samples from the surface 8 inches of Sassafras fine sandy loam soils were collected from the Virginia Truck and Ornamentals Research Station at Painter, Virginia. Samples were taken randomly from various fields of the series in order to obtain a variation in organic matter. Sassafras soils are deep, well-drained soils formed in coarse textured marine sediments of the lower Coastal Plains. The Sassafras series is classified in the current classification system as: Typic hapludults, fine-loamy, siliceous, mesic.

The samples were air dried and passed through a grinder to assure uniformity. In determining the effects of soil moisture on the reflection of Sassafras fine sandy loam, it was decided to use two basic soil samples. One sample contained 3.0% organic matter, the average of the farm, while the other was oxidized in a muffler furnace to less than 0.2% organic matter. Twelve 100 ml beakers were filled with soil from each sample and then sprayed with distilled water until completely saturated. Percent reflection was then determined throughout the moisture range of complete saturation to oven drying. When duplicate samples were removed from each beaker for reflection measurements, the remaining soil was used for the determination of percent moisture.

Organic matter was determined by the method outlined by Peech (1947) using sulfuric acid oxidation. All fifty samples were oxidized twice by two different technicians, and if the results showed any significant variation, they were analyzed again. Eight samples were then selected which covered the organic matter range of 1.0-9.0 percent. An additional sample was oxidized in a muffler furnace to less than 0.2% organic matter. Duplicate subsamples were again taken from each sample for reflection measurements.

A Hitachi Elmer-Perkins, Model 139, UV-U15 Spectrophotometer with a diffuse reflection attachment was used for all measurements. The wavelengths of 650 millimicrons and 900 millimicrons were selected for both variables. The 650 millimicron wavelength is near the peak absorption of chlorophyll, which is a sensitive range for both conventional and infrared films, while the 900 millimicron wavelength is near the upper range of the infrared film.

Results

Excess moisture above field capacity had little effect on percent reflection as shown in Fig. 12 and 13 regardless of wavelength. However, with a decrease in soil moisture from field capacity (1/3 atmosphere) to permanent wilting point (15 atmosphere), there was a rapid increase in percent reflection. The amount of increase was dependent on the organic matter content and was independent of the wavelength.

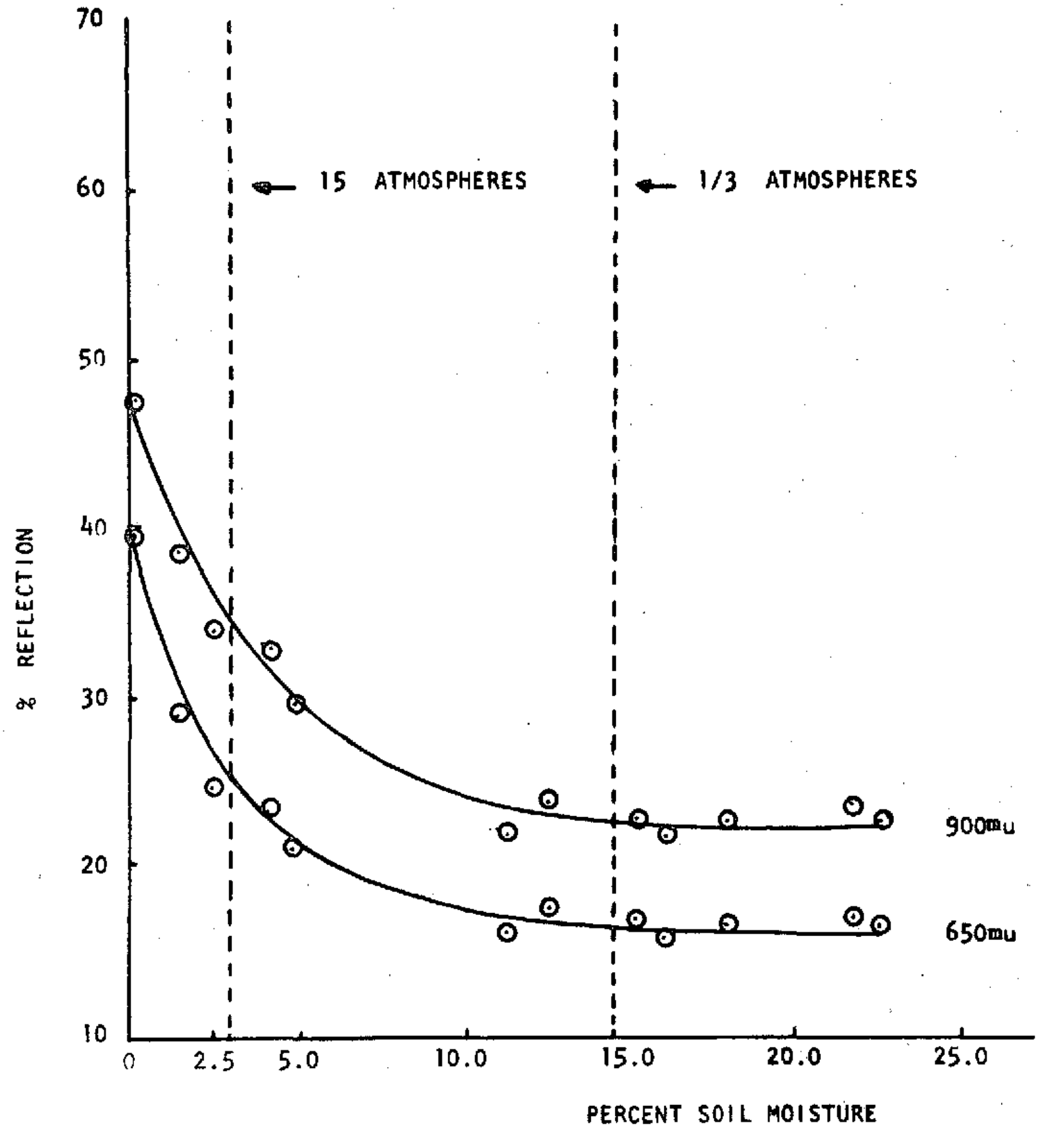

Fig. 12. Relationship of percent reflection to percent soil moisture for Sassafras fsl with 3.0% O.M. at 650 and 900 millimicrons.

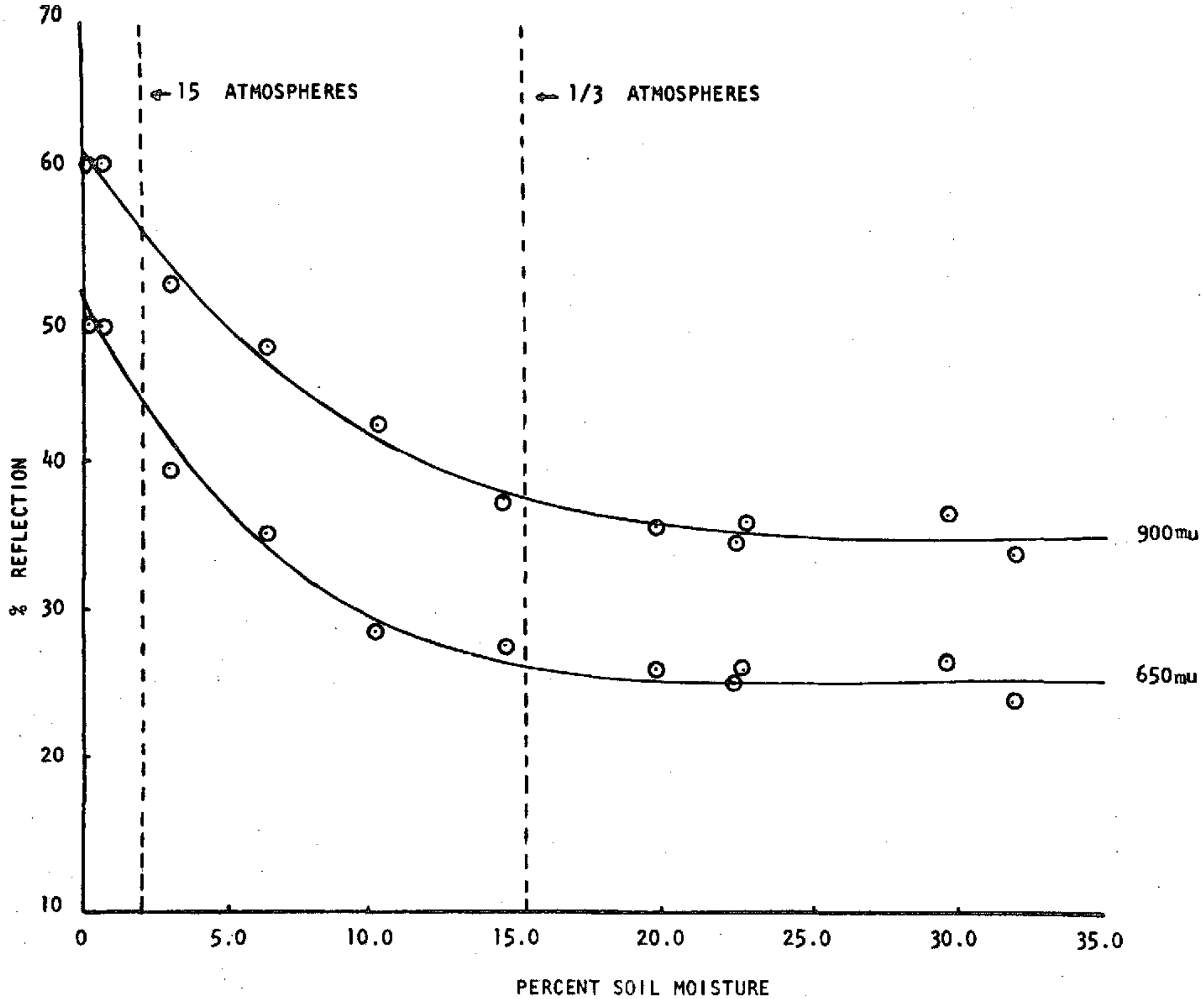

Fig. 13. Relationship of percent reflection to percent soil moisture for Sassafras fsl with 0.2% organic matter at 650 and 900 millimicrons.

The Sassafras sample with 3.0% organic matter averaged only a 0.7% increase in reflection with each 1.0% drop in soil moisture from field capacity. While the sample with less than 0.2% organic matter averaged 1.3% or nearly twice the increase. The high organic matter sample showed a much greater increase approaching permanent wilting point (2.1% from 5.0-2.5% moisture) than below field capacity (0.2% from 15.0-12.5% moisture). The low organic matter sample failed to show this increase near the permanent wilting point and maintained a fairly constant increase.

Below permanent wilting point the high organic matter curves show a rapid increase in percent reflection. These curves averaged 5.2% increase for each 1% drop in soil moisture. However, the low organic matter curves again failed to show this rapid increase in reflection as the soil dried to permanent wilting point and below. The shapes of the two sets of curves were independent of the wavelengths for each organic matter level (Fig. 12 and 13). Reflection values were constantly 6.0% higher for the 900 millimicron curve compared to the 650 millimicron curve at each moisture level for the 3.0% organic matter sample and 10.0% higher for the low organic matter sample.

The effects of organic matter may be shown in Fig. 12 and 13. At field capacity the curves for the 3.0% organic matter sample averaged only 19.5% reflection for both wavelengths while the low organic matter sample averaged 32.5% reflection. As the soils dried towards the permanent wilting point, the difference between the two sets of curves became even larger.

Fig. 14 shows the relationship of percent reflection to various levels of organic matter for air dried samples. Higher levels (5.0-9.0%) of organic matter failed to have any detectable effects on percent reflection. However, as the organic matter approached lower levels, there is a very rapid increase

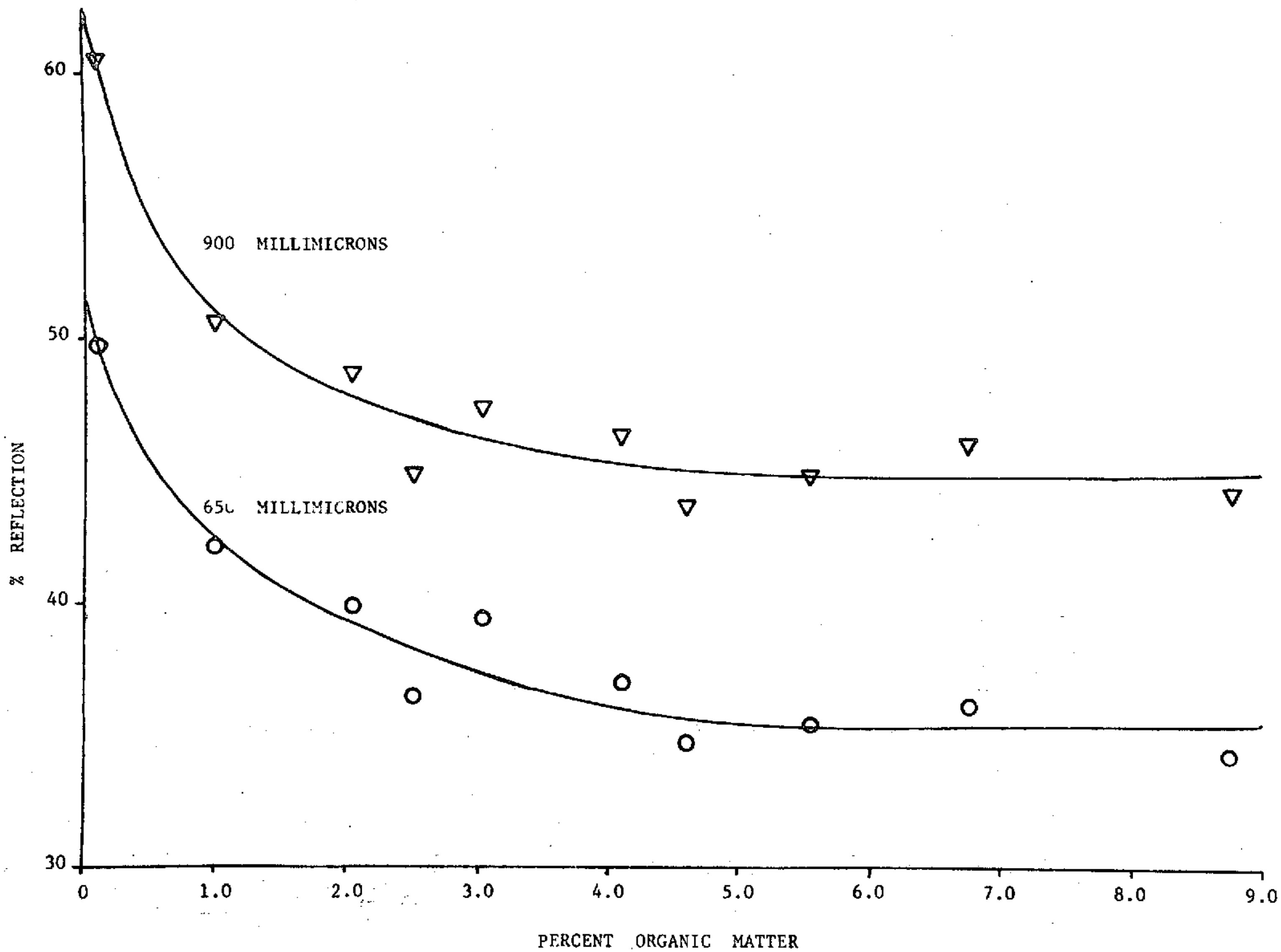

Fig. 14. Relationship of reflection for Sassafras fsl at 650 and 900 millimicrons to various levels of soil organic matter.

in percent reflection at both wavelengths. Both the 900 and 650 millimicron wavelengths had similar shaped curves, with the 900 millimicron curve being approximately 10% higher throughout. Variation in reflection between Sassafras soils with high and low organic matter levels was 15 percent.

Summary

The reflection of visible and infrared radiation from Sassafras fine sandy loam was strongly dependent on both moisture and organic matter content. Percent soil moisture variation from field capacity to oven drying caused an increase in percent reflection of 20 to 25% for both wavelengths and organic matter levels. These results agree closely with those of Condit (1970). This increase in percent reflection is a change of approximately 100% in total reflection for the sample with 3.0% organic matter. Therefore, failure to consider soil moisture levels could possibly mean an error of at least 100% in attempting to evaluate soil conditions from color or tones of aerial photographs.

Lack of variation in reflection above field capacity (1/3 atmosphere H_2O tension) was found at both 650 and 900 millimicrons. This indicates that other types of remote sensing might be more useful in evaluating very wet soils and conditions. Thermal scanners sensitive in the areas of water absorption could be more effective.

Variation in organic matter from high to low levels also caused a significant increase in percent reflection at both wavelengths. However, the magnitude (15%) was less than the variation due to soil moisture (20-25%) for air dried samples. At lower levels of organic matter more mineral fragments become visible and the reflection increased accordingly. In evaluating the effect of soil moisture, organic matter determines the shape of the curves.

The sample with less than 0.2% organic matter had a uniformly sloped curve from field capacity to air drying while the soil with 3.0% organic matter showed a rapid increase in reflection nearing the permanent wilting point. This rapid increase is associated with the strong affinity of organic matter for water.

Discrimination of Forest Types Utilizing Scanner Data

On November 5, 1970, a 12-channel scanner operating from 0.40-1.00 micrometers was utilized in an attempt to identify various crop and soil conditions occurring on the Virginia Truck and Ornamentals Research Station at Painter, Virginia. While classifying the various fields, it was decided to add a tree training class. This additional class allowed us to clearly determine field boundaries by showing tree border areas. Fields were thus much easier to locate on the gray scale map and contribute significantly to the success in classifying the various fields.

The training area selected for trees was located just north of Field K and was composed almost entirely of pines. Unlike most woodlots surrounding the farm, the 60' stand contained a high percentage of Virginia Pine (*Pinus virginiana*) 25-40 percent. The stand has a high basal area (120 sq. ft./acre); therefore, few open areas can be seen from above. In selecting this one tree class, it was assumed that stands with mixtures of hardwoods and pines, and those with lower basal areas would be classified to some extent as fields. These hypotheses became evident as the first computer classification of the flight line containing the tree training class was examined. Many field symbols appeared in forested areas.

Since the training class for trees was located in an area of 100% pine, classification for other woodlots with high basal areas (BA) displayed as field symbols could be assumed to be hardwoods. Even in areas of low BA, hardwood underbrush should show similar reflective responses as the overstory. Table 5 is a comparision of forest types using ground truth and scanner data. All codominant and dominant trees in several one-fifth acre plots (randomly selected in each woodlot) were totally tallied in order to determine the stand composition. In determining forest types by scanner data, 100 scanner points were selected for each woodlot. Points classified as trees were counted as pines and those classified as fields as hardwoods. As Table 5 shows, the scanner data can be used to accurately distinguish hardwoods from coniferous species.

Since conventional photography, if taken during the appropriate seasons, can be used to accurately distinguish hardwoods from conifers, it would be considerably more costly to use scanner type instruments to accomplish this. However, if scanners could be used to separate forest types based on stand size, density, or species composition a great deal of money and manpower could be saved. The U. S. Forest Service presently inventories the forest composition of each state at 6-8 year interval and at a high cost. If random flight lines could be set up for repeated evaluation, this could replace the present procedures. However, this is assuming that scanner type instruments will give the desired accuracy.

Seven type classes were thus selected which represented the forest types surrounding the farm (Table 6). These classes gave a range in stand size (height and diameter), density (basal area), and species composition often encountered on the Delmarva Peninsula. Training areas for the classes were selected for flight line 04 and then extended to the other flight lines.

Table 5. Comparison of forest types using ground truth and scanner data.

Woodlot #	Forest Type From Ground Truth	Forest Type From Scanner Data
1	80% Hardwoods	77% Hardwoods
2	90% Pine	92% Pine
3	60% Hardwoods	42% Hardwoods
4	60% Hardwoods	45% Hardwoods
5	70% Pines	95% Pine

Table 6. Classification by training areas (% of total samples).

Class	No. Samples	A	A1	B	B1	E	G	I	Sod	Crops
A - Loblolly 50-70'-High BA - 120	92	*25	2	2	39	17	2	12	0	1
A1-Loblolly 50-70'-BA<80	15	0	*7	20	0	13	33	13	7	7
B-Loblolly 15-30'-25% hdwd	30	23	3	*10	44	7	10	3	0	0
B1-Loblolly 15-30'-No hdwd	58	14	0	0	*74	7	2	3	0	0
E-Mixture Pine >50%	40	20	2	5	38	*25	2	8	0	0
G-Hardwoods Hdwd >70%	70	4	11	9	0	4	*56	0	10	6
I-Hdwds BA <90	28	18	4	4	50	7	7	10	0	0

*Classification from ground truth.

At first glance the classification of the training areas gave poor results (Table 6). However, combining similar classes often gave good results. Class A (Loblolly 50-70' tall and with a high basal area) had only a 25% classification accuracy, but an additional 45% of the samples were classified as smaller loblolly with similar basal area. Most other classifications were also improved considerably by combining similar classes. However, Class A1 and Class I were incorrectly classified. Nearly 50% of the A1-Loblolly training area was classified as hardwoods, and over 70% of the I-hardwood training area was classified as various types of pines. These two training areas were small woodlots surrounded by different vegetation classes. Because of the skewness of the flight lines, it is likely that several coordinates were not entirely within the desired training area. With the small amount of samples for certain training areas, this error becomes very large.

Accuracy of this classification may have been reduced for several reasons. First and probably the most important, was the previously mentioned small sizes of certain training areas. Some were small plantations which had very distinct boundaries and because of the skewness of the flight lines, it is doubtful that the exact coordinates were given to the computer. Thus, all samples for a training area were not within the desired forest type. Classes with low basal areas usually had a large classification error, mainly because of the failure to take into account the response of the lesser vegetation. Autumn leaf fall may have also reduced the hardwood leaf area often exposing pine and holly (Ilex) understories.

Because of the poor results found for the classification of the training areas, no attempt was made to classify woodlots outside these areas. The computer printouts and gray scale map did, however, show distinct tree vegetation boundaries, but these are very difficult to locate on a base map because of the magnitude of skewness which occurred. This problem must be reduced before a system of classifying vegetation for any given large area may be produced.

Greenhouse Study

With the development of better photographic equipment and film processing, new possibilities for utilization of aerial photography in agriculture has arisen. Among these are the detection of crop diseases, nutrient deficiencies, insect damage appraisals, and identification of plant species. Increasing cost of ground surveys and inaccuracies of questionnaires have forced attention on aerial photographic and other forms of remote sensing as the answer to these problems.

Recent researchers report that nutrient deficiency, drought, and high salt levels can be detected by leaf reflection in the photographic region of the spectrum. Benedict and Swidler (1961) found only slight variation in reflection for leaves of various chlorophyll content of soybeans and valencia orange between 0.720-1.000 micrometers. The greatest variation occurred at 0.625 micrometers, with chlorotic leaves reflecting a much higher percentage of light. Thomas et al. (1967) found significant variation in reflection from 0.38 to 0.7 micrometers due to nitrogen deficiency. He associated this with lower chlorophyll contents. Greenhouse studies by Ward (1969) and Richardson et al. (1969) showed no effects of drought, high salt, and four nutrient deficiencies on reflection of leaves of maple, corn, squash, and sorghum at wavelengths between .80-1.20 micrometers. Species showed only slight variation in reflectance. However, Fritz (1967) found significant variation between leaves of field grown tree species at .72 to .90 micrometers. Gausman et al. (1969) felt that the lack of variation often found in greenhouse studies was due to the development of leaves all of which contained similar cell arrangement. Weber and Olson (1967) found leaves of tree species which developed during satisfactory moisture conditions have the same reflective property regardless of moisture stress after maturity. However, leaves developing under various conditions of moisture stress will later show variation in reflection.

Objectives of this experiment were to determine what effect fertilizer deficiencies and drought have on the chlorophyll content and reflection of Irish potatoes (Solonum tuberosum var. pungens) grown in the greenhouse and to determine what effect chlorophyll content and reflection have on color IR photographs of field-grown Irish potatoes.

Methods

The greenhouse experiment was carried out in two parts. One in the fall of 1970 and the other in the spring of 1971. In 1970 thirty-two pots (two liter volume) were filled with Sassafras fine sandy loam surface soil (fine loamy, siliceous, mesic Typic Hapludults) from the Virginia Truck and Oramentals Research Station at Painter, Virginia. In 1971 sixteen pots were filled with Sassafras fine sandy loam and 16 pots were filled with a sterile sand.

Three or four Irish potato wedges (var. pungens) were planted in each pot in order to obtain two healthy plants per pot. Fertilizer was added to half of the pots at the beginning of each experiment at a rate of 454 kg per hectare of a 10-10-10 mixture. Fertilizer treatments were repeated at six weeks in 1970 and five weeks in 1971. Four fertilizer-water combinations were employed for both years. These were F-AM (fertilized-adequate moisture), F-MS (fertilized-moisture stress), NF-AM (no fertilizer-adequate moisture), and NF-MS (no fertilizer-moisture stress). The AM (adequate moisture) plants were watered to 15% soil moisture (dry weight basis) daily (slightly above field capacity of 14.2%) while the plants under moisture stress were watered to only 5% soil moisture (dry weight basis).

Height measurements were made at six and eleven weeks in 1970 and at five and ten weeks in 1971 for all plants. Four typical leaves were selected from each treatment for reflectance measurements between 0.60-1.00 micrometers in 1970 and 0.40-1.00 micrometers in 1971. A Perkin-Elmer Model No. 139 Spectrophotometer with a special reflectance attachment was used for all measurements. Typical leaves were also removed from each plant at each sampling date for chlorophyll analysis. Chlorophyll content reported here on a dry weight basis was determined by first extracting with 80% ethanol and then following the procedures of Dozier (1971). Total plant weight and leaf area were determined at the completion of the experiment in 1971.

Throughout the 1971 growing season biweekly flights of the Virginia Truck and Oramentals Research Station at Painter, Virginia, were made by helicopter at 150-300 meters utilizing Kodak color aerial infrared Ektachrome #2443 with a Wratten #12 filter and infrared black and white #2424 film with a Wratten #25A filter. During each flight ground truth data was taken of each field and section. Leaves from selected Irish potato experiments were collected for chlorophyll and reflection measurements. Ground photography was also made of the same fields.

Results and Discussion of the 1970 Experiment

The effect of drought and fertilization combinations on growth expressed as height of Irish potatoes is shown in Table 7. Plants receiving adequate water had significantly greater heights (99% level) at 6 and 11 weeks than the moisture stressed plants regardless of fertilization treatment. Scheffe's test also showed that there was no significant difference among plants receiving the same water regime. The results show that a moisture stress effect was produced in 1970, but no fertilizer response occurred. Residual soil nutrients were high enough to give similar plants for all treatments.

Chlorophyll content was measured at six and eleven weeks. The results, Table 7, show that neither drought nor fertilization had any effect on chlorophyll content at six weeks. However, at eleven weeks the NF-AM treatment had a significantly lower chlorophyll content than the other three treatments, while the F-AM treatment was significantly lower than both MS treatments (Scheffee's test at 99% level).

Results of the reflection values at six and eleven weeks were very similar regardless of treatment. Differences in reflection values for all treatments at six and eleven weeks of age were small (less than 5% at all wavelengths) and clearly indicate that the differences in chlorophyll content had little effect on percent reflection between .60-.95 micrometers. Gausman et al. (1969a) found that this failure to obtain a reflection variation might be due to the development in the greenhouse of leaves with similar structure (shade type) and reflection. However, Weber and Olson (1967) reported that conditions during initial leaf development determines later leaf reflection and not treatments or conditions applied after leaf maturity.

Table 7. Variation in height and percent chlorophyll content of Irish potato leaves (var. pungens) as affected by drought and fertilization at six and eleven weeks in 1970. Each value is an average for sixteen plants.

Six Weeks			Eleven Weeks		
Treat-ment	Height (cm.)	Percent Chlorophyll	Treat-ment	Height (cm.)	Percent Chlorophyll
F-AM	35.6(A)	0.47(A)	F-AM	48.0(A)	0.50(B)
F-MS	17.8(B)	0.50(A)	F-MS	30.0(B)	0.64(A)
NF-AM	30.0(A)	0.47(A)	NF-AM	43.0(A)	0.38(C)
NF-MS	17.8(B)	0.45(A)	NF-MS	31.8(B)	0.64(A)

F - Fertilized
NF - No fertilizer
AM - Adequate Moisture
MS - Moisture Stress

Enteries followed by the same letter (A, B, or C) in each column are not significantly different as determined by Scheffee's test at $p = 0.01$.

Results and Discussion of the 1971 Experiment

The effects of fertilization expressed as total plant dry weight, height, and leaf area are shown in Table 8. The F-AM plants grown in the sterile sand had significantly greater dry weights, heights, and leaf areas at ten weeks. The F-MS treatment had a significantly greater chlorophyll content; this indicated that a fertilization effect had been achieved.

Plants grown in the Sassafras soil again were strictly dependent on soil moisture with the AM treatments having significnatly greater dry weights and heights regardless of fertilization at ten weeks (Table 8). However, the F-AM treatment had a significantly larger leaf area than the other treatment at ten weeks. Fertilized plants had a significantly greater chlorophyll content (regardless of moisture level) at five weeks, but not at ten weeks.

Table 8. Variation in total plant dry weight, height, leaf area, and chlorophyll content of leaves of Irish potatoes (var. pungens) as affected by drought and fertilization at five and ten weeks in 1971. Each value is an average of eight plants.

	Five Weeks		Ten Weeks			
Treatment	Height (cm.)	Percent Chlorophyll	Total Plant Dry Wt. (g)	Height (cm.)	Leaf Area $(cm.)^2$	Percent Chlorophyll
Sassafras						
F-AM	39.4(AB)	0.87(A)	27.2(A)	85.1(A)	380(A)	0.56(A)
F-MS	21.6(C)	0.81(A)	6.9(B)	38.1(B)	108(B)	0.65(A)
NF-AM	34.6(A)	0.32(C)	16.6(A)	96.5(A)	195(B)	0.15(B)
NF-MS	29.2(BC)	0.58(B)	5.7(B)	49.5(B)	91(B)	0.44(A)
Sand						
F-AM	57.2(A)	0.38(B)	41.6(A)	107.2(A)	548(A)	0.26(B)
F-MS	35.6(B)	0.80(A)	16.0(B)	68.1(B)	272(B)	0.57(A)
NF-AM	25.4(B)	0.28(B)	4.7(C)	45.7(B)	43(C)	0.13(C)
NF-MS	25.1(B)	0.38(B)	4.6(C)	48.3(B)	52(C)	0.19(BC)

F - Fertilized
NF - No fertilizer
AM - Adequate moisture
MS - Moisture stress

Entries followed by the same letter (A, B, or C) in each column are not significantly different as determined by Scheffee's test at $p = 0.05$.

Reflection values were similar at five weeks for plants grown in both the sand and Sassafras soil. The non-fertilized plants had an approximate 5% higher reflection in the visible spectrum compared to the fertilized plants and were similar in the infrared region. However, results at ten weeks (Fig. 15) showed significant variations. Fertilized plants grown in sand had a lower reflection (15-25%) between .500-.675 micrometers. No reflection difference occurred in the IR range. The non-fertilized adequately watered plants grown in the Sassafras soil had a significantly higher reflection between .500-.675 micrometers.

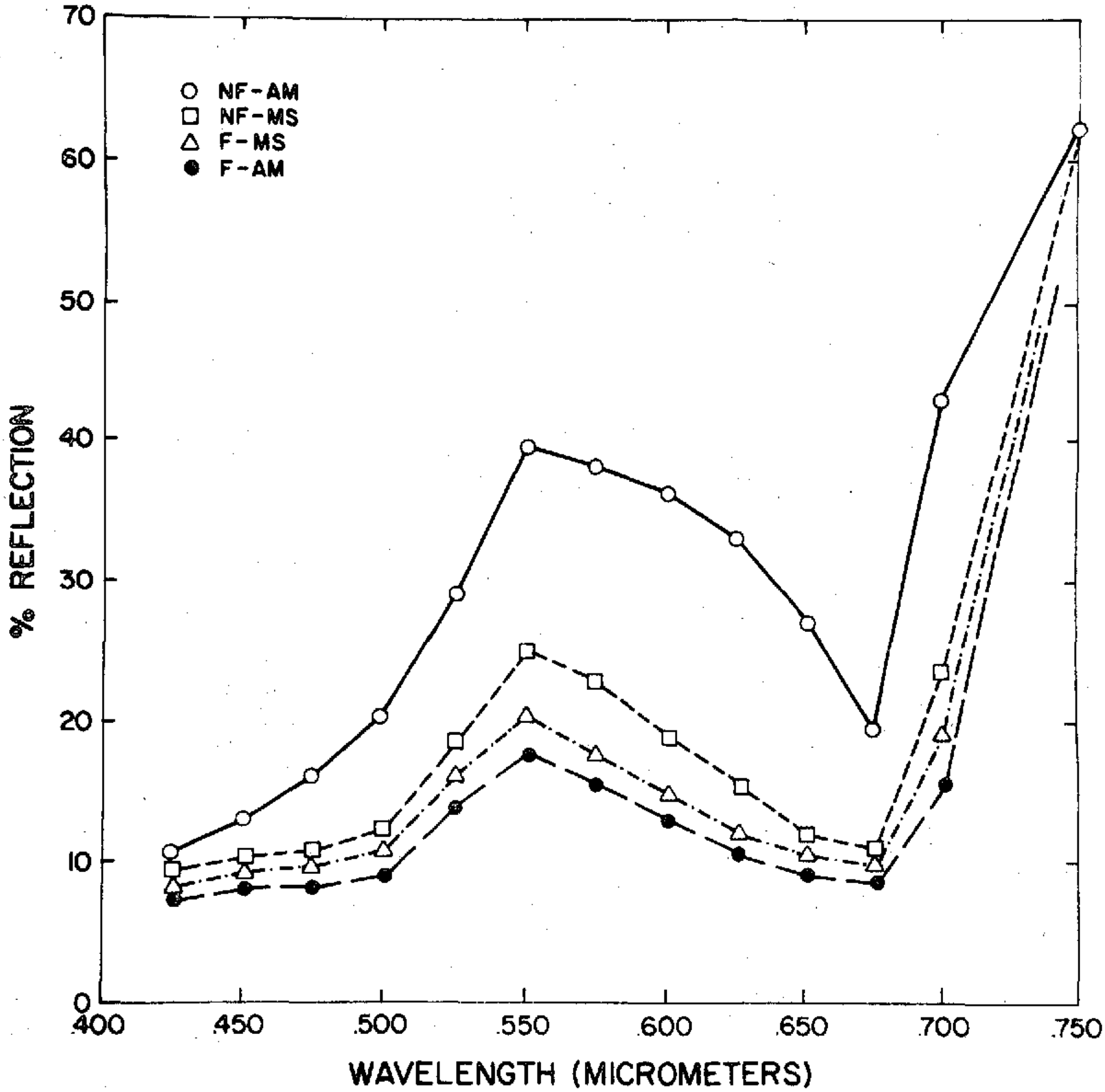

Fig. 15. Effect of fertilization and moisture stress at ten weeks on the reflection of Irish potato (var. Pungens) leaves in the photographic region of the spectrum, 1971.

In the 1971 experiment added care was taken to insure moisture stress even during pre-emergence germination. This treatment stress was not applied in 1970 until the plants were well above ground. The combination of the two experiments thus agree with the results of Weber and Olson (1967) who found that leaf reflection variations depend on the treatments applied to the plants during initial leaf development. Recently Stevens (1972) found an early infrared decrease in reflection only if the elm was infested with Dutch elm disease early in the growing season, while a similar decrease in the infrared region was not detected in later season infection until the leaf was almost crisp brown.

Field Results and Discussion

Even though distinct chlorophyll differences were often found throughout the growing season between different treatments of the field grown pungo variety of Irish potato, reflection variations were usually minute. Any variation which did occur was limited to a narrow portion of the visible spectrum. These field results agree with the 1970 experiment and indicate that adequate moisture during the early part of the 1971 growing season led to the development of leaves with similar type structures and resulting in similar reflection values.

Even in a few cases where reflection values were significantly different between treatments, no color variation could be detected on the color IR film. One possible reason for the lack of response is documented by Myers (1970). He found that stacking of leaves, higher LAI (Leaf Area Index) had no effect on reflection in the visible portion of the spectrum, indicating that reflection of visible light from surfaces is from the topmost exposed leaf layer. In the near infrared, however, stacking from a LAI of 1 to a

LAI of 4 almost doubled the reflectance. Further increases in LAI meant only small increases in reflection. Thus, high LAI's would compensate for chlorotic conditions by reflecting similar amounts of radiation and developing similar amounts of the cyanic or infrared sensitive layer of the color IR film.

An example of differences in chlorophyll content of leaves of Irish potatoes and how they appear on color IR was found on July 14, 1971. The darker 6HS-9 variety had a 0.7% chlorophyll content while the lighter superior variety had less than a 0.5% content. Reflection values showed a 10-15% variation in the visible spectrum only. Even with this significant variation in chlorophyll content the two varieties appeared as similar red colors on infrared photographs. Only variations in ground cover were evident. An isodensiometer also gave similar density values for the two varieties.

Conclusions

In order to obtain reflection variations (in the photographic region of the spectrum) between leaves with significantly different chlorophyll contents from different plants, it is necessary to subject these plants to fertilizer and drought treatments during initial leaf development. Failure to apply the treatments during initial leaf development will lead to leaves with similar leaf structure and reflection characteristics.

Aerial photography indicates that high leaf area indices (normally found for most crop species) will give similar reflection and develop similar amounts of the infrared sensitive layer of color infrared film, regardless of the reflection of the upper most layer of leaves. Therefore, color film which is sensitive only to the upper most leaf layer might possibly be better used in detecting chlorotic conditions.

Weather Data

The weather data collected at the environmental monitoring station has been transferred from charts to table form. This information is on file and available for use.

Recording of solar radiation was started March 10, 1971. Table 9 gives a monthly summary of solar radiation values for 1971 and 1972. Note that these values are for hours of clear skies. Also the values given for each hour is an average of all the values collected at that hour during the month. In most cases we note from the table that the radiation increases from 0.00 at sunrise to a high of .77-1.31 langleys around 1200 (EST) and drops again to 0.00 by sunset.

Soil temperatures are measured at regular intervals at several depths in the soil profile and under different vegetative conditions. The average surface (0-2 inches) soil temperatures under bare fields and in woods (loblolly pines) are given in Table 10 for 1971 and 1972. The average maximum and minimum temperatures for each month are also reported.

Table 9. Monthly summary for 1971 and 1972 of solar radiation values in langleys (clear hours only) at the Virginia Truck and Ornamentals Research Station, Painter, Virginia.

		Time (EST)														
Month	Year	0500	0600	0700	0800	0900	1000	1100	1200	1300	1400	1500	1600	1700	1800	1900
January	1971	DATA NOT RECORDED														
	1972	0.00	0.00	0.00	0.20	0.41	0.58	0.73	0.80	0.78	0.69	0.51	0.28	0.06	0.00	0.00
February	1971	DATA NOT RECORDED														
	1972	0.00	0.00	0.04	0.24	0.49	0.69	0.86	0.92	0.91	0.83	0.67	0.42	0.17	0.00	0.00
March	1971	0.00	0.00	0.10	0.30	0.58	0.78	0.95	1.05	1.00	0.92	0.74	0.52	0.23	0.04	0.00
	1972	0.00	0.00	0.18	0.45	0.69	0.91	1.04	1.12	1.09	0.98	0.80	0.57	0.29	0.06	0.00
April	1971	0.00	0.03	0.25	0.55	0.78	0.96	1.05	1.05	1.01	0.92	0.78	0.56	0.30	0.04	0.00
	1972	0.00	0.13	0.37	0.65	0.89	1.08	1.23	1.30	1.28	1.14	0.95	0.70	0.42	0.16	0.00
May	1971	0.00	0.12	0.39	0.67	0.89	1.05	1.16	1.19	1.17	1.05	0.89	0.66	0.39	0.13	0.00
	1972	0.02	0.23	0.46	0.76	1.00	1.16	1.27	1.31	1.28	1.19	1.02	0.78	0.50	0.24	0.04
June	1971	0.00	0.14	0.36	0.60	0.82	1.02	1.14	1.17	1.16	1.04	0.88	0.66	0.42	0.18	0.00
	1972	0.09	0.27	0.52	0.79	1.00	1.17	1.30	1.30	1.31	1.21	1.04	0.80	0.54	0.28	0.13
July	1971	0.00	0.13	0.36	0.63	0.85	0.91	1.16	1.16	1.13	1.08	0.90	0.71	0.44	0.21	0.00
	1972	0.04	0.20	0.42	0.66	0.91	1.10	1.23	1.27	1.27	1.19	1.02	0.81	0.50	0.28	0.12
August	1971	0.00	0.05	0.26	0.51	0.78	0.95	1.08	1.08	1.11	1.01	0.87	0.57	0.38	0.10	0.00
	1972	0.00	0.14	0.35	0.64	0.90	1.08	1.23	1.29	1.26	1.20	1.01	0.77	0.49	0.22	0.03
September	1971	0.00	0.11	0.28	0.55	0.80	1.01	1.11	1.17	1.09	0.98	0.80	0.57	0.30	0.10	0.00
	1972	0.00	0.13	0.30	0.59	0.82	1.02	1.14	1.14	1.07	1.01	0.85	0.57	0.29	0.11	0.00
October	1971	0.00	0.00	0.18	0.43	0.68	0.84	0.97	1.00	0.95	0.83	0.66	0.42	0.17	0.00	0.00
	1972	0.00	0.00	0.19	0.45	0.70	0.91	1.05	1.02	0.98	0.87	0.68	0.41	0.15	0.00	0.00
November	1971	0.00	0.00	0.08	0.28	0.49	0.67	0.79	0.82	0.79	0.66	0.45	0.21	0.01	0.00	0.00
	1972	0.00	0.00	0.13	0.30	0.51	0.71	0.83	0.84	0.81	0.68	0.47	0.21	0.09	0.00	0.00
December	1971	0.00	0.00	0.00	0.17	0.37	0.57	0.70	0.75	0.70	0.58	0.38	0.18	0.00	0.00	0.00
	1972	0.00	0.00	0.00	0.18	0.38	0.57	0.72	0.77	0.74	0.63	0.41	0.20	0.06	0.00	0.00

Table 10. Average surface (0-2 inches) soil temperatures and daily maximum and minimum air temperatures for 1971 and 1972 at the Virginia Truck and Ornamentals Research Station, Painter, Virginia.

		Soil Temp.									
		Fields	Woods	Fields	Woods	Fields	Woods	Fields	Woods	Air Temp.	
Month	Year	0100		0700		1300		1900		Max.	Min.
January	1971*	38	42	38	42	40	42	38	42	43	24
	1972	46	49	45	48	51	51	47	49	52	33
February	1971*	40	42	40	42	46	44	43	43	52	29
	1972	41	41	48	43	44	44	47	45	49	30
March	1971	48	49	47	49	53	51	52	50	55	34
	1972	45	47	44	47	60	54	47	47	55	36
April	1971	57	54	56	54	66	56	62	55	65	40
	1972	53	54	55	55	78	65	56	55	65	43
May	1971	59	56	58	55	75	57	64	57	73	52
	1972	60	60	62	60	80	65	62	61	72	54
June	1971	62	59	61	58	79	60	73	61	83	64
	1972	65	66	72	67	85	69	69	67	79	60
July	1971	70	68	69	67	92	69	81	70	86	68
	1972	73	74	78	74	99	76	78	74	86	66
August	1971	68	70	68	69	87	72	78	71	85	66
	1972	70	71	75	71	98	75	76	72	85	62
September	1971	62	65	60	64	91	67	69	66	80	63
	1972	64	65	65	65	83	68	66	66	80	59
October	1971	62	63	60	63	72	64	64	65	73	59
	1972	53	56	53	56	64	58	54	56	66	45
November	1971	45	49	43	48	52	51	47	49	59	40
	1972	--	--	--	--	--	--	--	--	57	37
December	1971	43	45	42	44	48	47	46	46	60	40
	1972	--	51	--	51	--	54	--	52	56	39

*Measurements were taken at 0300, 0900, 1500, and 2100 respectively during January and February 1971.

STUDY OF CAROLINA BAYS VIA REMOTE SENSING TECHNIQUES

Unusual topographic features were detected on color infrared photographs while evaluating soil and vegetation patterns near the Virginia Truck and Ornamentals Research Station during the fall of 1972. The soil features appeared circular to ellipsoidal in shape and varied in size. The outer rims were light in color whereas the lower central portions had much darker colors. Initial photographic evaluations suggested the topographic features were possibly of cultural origin, perhaps related to ancient Indian campsites or kitchen middens. Closer ground investigation of the features and broader photographic evaluations indicated the landscape features were widely distributed throughout Accomack and Northampton Counties. A preliminary pedologic study of the soil features suggested they were landscape features commonly known as Carolina Bays. As a result of this "spin-off" of the comprehensive research project in remote sensing, a detailed investigation was initiated to study the Carolina Bays on Virginia's Eastern Shore via remote sensing techniques and pedological methods.

Background on Carolina Bays

The presence of Carolina Bays on Virginia's Eastern Shore was noted in the 1917 Soil Survey of Accomack and Northampton Counties (Stevens, 1920) which reported the level topography is broken by low ridges that often totally enclose basin-like depressions. These depressions have also been referred to on the Eastern Shore as whale wallows and Maryland basins (USDA, 1970). A review of the literature reveals an intriguing background on the subject involving much controversy regarding the origin of the Carolina Bays.

Carolina Bays reportedly occur along the Atlantic Coastal Plain from northeast Florida to southern New Jersey with estimates of perhaps one half million such features (Prouty, 1952). Some of the earliest reported scientific works to draw attention to these peculiar basin-like depressions concerned bays in South Carolina (Toumey, 1848). Toumey, a South Carolina state geologist, suggested the bays were formed by the action of springs rising to the surface of a sandy plain. Later work advocated an origin due to the action of winds and waves on sand bars of shallow coastal embayments producing depressions enclosed by sand ripples (Glenn, 1895).

The term "Carolina Bay" apparently was proposed in 1933 to refer to the ovate, oval, or elliptical bays enclosed by low sandy ridges (Melton and Schriever, 1933). The term seemingly originated because the depressions were first studied in the Carolinas where they were noted to widely occur and because the basins commonly contained various species of bay trees (Frey, 1949). Later publications proposed the term Neptune rings to describe the unusual depressions (Cooke, 1945), but Carolina Bays apparently was the preferred description of the scientific community.

World attention was attracted to the subject when Melton and Schriever (1933) proposed a meteoritic origin for the Carolina Bays. These workers proposed the bays were formed by the infall of meteorites of a probable comet mass traveling in a general southeast direction and hitting the earth at a small angle to the horizontal. Contrasting theories concerning the origin of the bays were proposed by C. Wyth Cooke (1933) who interjected new ideas to the controversy. Cooke (1933) proposed that bays are formed through construction of crescentic keys and segmented lagoons via forces of a dominant southeast wind. He proposed the wind created elliptical currents that scooped out elliptical depressions with the long axis parallel to the direction of the wind. Melton (1934) contested the views of Cooke. He proposed that if the meteoritic theory was untenable, his next choice was bay formation by submarine scour resulting from eddies, currents, or undertow. MacCarthy (1937) reported Carolina Bays were formed by the shock-waves accompanying a shower of large meteorites and not directly by the impact of the meteorites upon the earth. He further stated that bays are much larger than the meteorites that produce them. Later, Cooke (1940) proposed a new theory stating that bays were created in any confined body of water by the formation of elliptical eddies directed through gyroscopic effects of the earth's rotation.

Other interesting theories to account for the origin of Carolina Bays developed in the decades of the 1930's through the 1950's. Johnson (1936) purported that Carolina Bays are essentially the product, either directly or indirectly, of solution, and the encircling rims represent accumulations of wind drift sand. Later, he proposed a new theory of bay origin that included the upwelling of artesian springs in association with ground water to produce circular rims (Johnson, 1942). A unique theory also involving artesian springs was advanced by Grant (1945), who proposed that hovering activities of spawning schools of fish are responsible for the formation of the shallow sand-rimmed depressions. Supposedly, such activities occur where artesian springs of fresh water appear in near-shore marine areas.

Black and white aerial photographs were used in increasing fashion to study the bays (Frey, 1949) and to delineate them (Frey, 1950). He reported a general decrease in the number of Carolina Bays with decreasing elevation on the Coastal Plain terraces. Odum (1952) used aerial photographs to determine that a general northwesterly to southeasterly orientation of Carolina Bays exists in the Carolinas. He stated that the appearance of Carolina Bays on aerial photographs resembles cookie dough after the cookies have been removed.

Essentially much of the research work on Carolina Bays was conducted in the Carolinas and it was directed largely to gain an understanding of the origin of the bays. Most of the researchers agree that water probably has had some effect on the formation of the Carolina Bays that occur in the sandy soil materials of Atlantic Coastal Plain.

Preliminary Investigation

Study Area

The Carolina Bay investigation was conducted in Accomack and Northampton Counties, Virginia. Forming part of the Delmarva peninsula, Accomack and Northampton Counties, Virginia, are commonly referred to as the Eastern Shore of Virginia. The counties are bounded on the east and south by the Atlantic Ocean, on the west by the Chesapeake Bay, and on the north by the State of Maryland. The counties comprise a land area of about 682 square miles. The mean width of Accomack County, the upper county, is about 8 miles and Northampton County has an average width of about 6 miles. The two county peninsula has a northeast-southwest trend comprising a length of some 75 miles.

The study area is characterized by 3 main physiographic divisions, consisting of the mainland, the off-shore coastal islands, and the salt marshes. The mainland portion has generally level topography. Few points in either county exceed 50 feet above sea level. The drainage divide generally bisects the counties, diverting the drainage on the western side to Chesapeake Bay and the eastern side to the Atlantic Ocean. The principal drainage consists of tidal estuaries, locally called creeks (Stevens, 1920).

Both counties are entirely within the Coastal Plain Province. The soils have developed in deep marine sediments. Gravimetric surveys indicate about

4,000 feet of sediments overlie basement rock in the Exmore-Melfa area, and the thickness increases to about 7,500 to 8,000 feet near Wallops Island (Johnson and Sweet, 1970). Apparently, basement rock has not been reached in drilled wells of Northampton and Accomack Counties (Johnson and Sweet, 1970). However, these workers reported a well near Salisbury, Maryland, penetrated basement rock at 5529 feet.

Methods

Photographic analyses were made of remote sensing imagery covering the two county area utilizing Richards Light Tables (Model GFL-918X) and supplemental 10X magnification lens. The primary imagery evaluated consisted of color-infrared photography (2443) taken at an altitude of 10,000 feet using a C-130 aircraft and RC-8 sensor (W12 + 2.2 AV filter, and 6 inch lens) by NASA (mission 181) on June 8, 1971. Infrared black and white imagery of this flight was also examined. High altitude color infrared imagery (3443) taken at an altitude of 65,000 feet by a NASA U-2 aircraft on January 7, 1972, was also evaluated to determine the effects of increasing altitude on recognition capability to detect Carolina Bays.

Ground truth investigations were made of about 25 areas previously selected from photo-evaluation to confirm their identification as Carolina Bays. Soil investigations were made on Carolina Bays near Nelsonia and Belle Haven at higher elevations, and near sea level at Guard Shore in Accomack County, and at intermediate elevations near Eastville in Northampton County.

Results and Discussion

Over 150 landscape features were identified by imagery evaluations and subsequently classified as Carolina Bays following ground observations of representative areas of wide distribution in the two counties. The basin-like depressions were determined to occur from the lower salt marshes to the higher elevations of the mainland. Greater numbers of the Carolina Bays appeared to be concentrated on the higher ridges that lie roughly northeast to southwest and comprise the center of the two counties. The bays ranged in shape from circular to ellipsoidal and the orientation varied considerably. The topographic features ranged in size from about 200 yards to nearly a mile in diameter.

Numerous Carolina Bays were identified near Nelsonia appearing almost in clusters and often bounding or overlapping other bays (Fig. 16). The higher surrounding rims of the bays clearly delineate the features and they appear as much lighter color than the darker, wetter central portions of the bays. Although surface drainage patterns and darker colored soil areas randomly occurred (Fig. 16) the bays could readily be delineated. However, bay features located entirely in densely wooded areas of rather uniform vegetation could not be identified readily. Stereoscopic photographic coverage enhances evaluations via stereoscopic examinations in the wooded areas.

Very marked vegetation differences associated with the soils of the Carolina Bays located in lower coastal areas near sea level were noted on the color infrared imagery. The presence of woody vegetation on the higher, better drained rims of the bays clearly delineate the rims from the lower, wetter centers of the bays as illustrated in the areas near Guard Shore (Fig. 17). The ellipsoidal, circular, and partially completed rims of Carolina Bays in the Guard Shore area indicate the variety of conditions

Fig. 16. Color infrared photograph taken at 10,000 feet altitude illustrating Carolina Bays of various sizes and orientation near Nelsonia, Virginia. Outlines of several bays can be seen (see arrows).

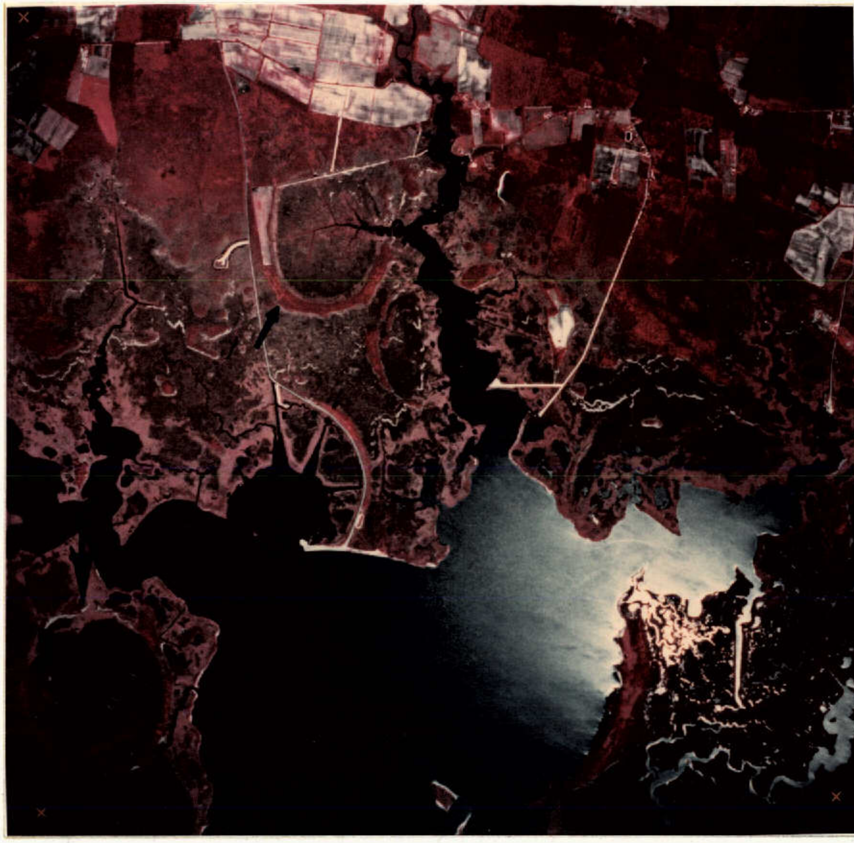

Fig. 17. Color infrared photograph taken at 10,000 feet altitude illustrating Carolina Bays in marsh areas of the Chesapeake Bay near Guard Shore, Virginia. This is an illustration of how the presence of woody vegetation on the higher rims of the bays (see arrows) clearly delineate the rims from the lower wetter centers of the bays.

noted in the lower elevations primarily on the Chesapeake Bay side of the peninsula. The rims of many of the bays in the marsh areas are a few feet above sea level, whereas the central basins are often submerged during high tide. The crescent shaped or partially completed rims raise several pertinent questions concerning the status of formation or possible degeneration or migration.

Photographic evaluations of the imagery of the two counties indicated interesting land-use trends that were associated with the Carolina Bays. In the lower elevation areas, particularly, it was observed that roads were commonly constructed on the higher lying rims of the Carolina Bays (Fig. 17). The rims were also noted to be common sites for cemeteries and building sites throughout the peninsula. Ages of some of the cemetaries observed on the rims of bays suggest this may be a very old practice.

Very marked differences were noted in agronomic production on the Carolina Bays in several instances. Differences in crop growth and yields were observed which contrasted plant growth in the wetter centers of the bays and the higher, better drained rims. Lack of a natural drainage outlet in the enclosed bays was readily observed. Differences in wind and water erosion conditions between the rims and depressed centers of the bays were also noted.

Although the larger Carolina Bays could still be detected on the color infrared imagery taken at 65,000 feet altitude, many of the smaller bays could not be identified without considerable magnification (Fig. 18). The color infrared photograph of the southern part of the peninsula (Fig. 18) is quite conducive for photographic evaluations of land-use and vegetation type analyses, but many of the previously identified bays were not detectable on this high altitude imagery. However, the panoramic view reveals the general

Fig. 18. High altitude color infrared imagery obtained via U2 aircraft at 65,000 feet showing panoramic view of the southern end of the Eastern Shore of Virginia. Only the larger Carolina Bays are detectable at this altitude.

occurrence pattern of the larger Carolina Bays that generally parallels the central ridge extending northeast.

Soils

Carolina Bays Considerably Above Sea Level - Soil investigations indicated the rims of bays were comprised of well-drained, moderately well-drained, and lesser amounts of excessively drained soils. The rims of the bays investigated were comprised of dominantly two to three soil series, all of which were classified as typic hapludults, fine-loamy, siliceous. The lower centers of the bays were comprised of somewhat-poorly and poorly drained soils which exhibited more variation than soils comprising the rims. The soil comprising the interior portions of the bays could usually be classified as typic ochraquults, clayey, mixed, or as aquic hapludults, clayey, mixed. During field studies in the spring of 1973 the ground water table of the rim soils was not detected within depths of 60 inches, whereas it was encountered within 25 inches of the surface in the soils comprising the interior part of the bays. Generally soils of the rims exhibited better pedogenic development, had brighter color and sandier surfaces, contained less clay and silt in the subsoil and less organic matter in the surface, and they were considerably more droughty than soils of the interior of the bays.

Mineralogical analyses indicated the sand and silt fractions are dominantly quartz and amorphous constituents. Clay fractions are composed of chloritized vermiculite, kaolinite, quartz, and amorphous iron and aluminum oxides.

Carolina Bays Near Sea Level - Interesting pedological relationships exist between soils comprising the bays of higher elevations contrasted to those located near sea level. Similar trends were noted to exist with the higher lying bays regarding the degree of soil development. The soils comprising the rims of the bays located near sea level exhibited some degree of pedogenic development, whereas soils in the interior portions of these bays were largely stratified and undifferentiated. Horizonization was evident in the rim soils which were dominantly comprised of somewhat-poorly to moderately well-drained soils with water tables encountered at depths of 30 to 50 inches. Weak horizon development and related morphological properties of texture, color, and consistency suggest the soils have active eluviation and illuviation processes of soil formation. In contrast, soils of the interior portions of these low-lying bays had very little soil development, and they were characterized by surface high in organic matter and subsoils of a stratified nature containing high silt content. These soils are innundated completely at high tide levels and appear to be saturated continuously. Much greater content of both silt, organic matter, and course fragments were detected in the soils of the lower bays than those located at higher elevations.

Soil investigations indicate the soils comprising the bays near sea level are in the initial stages of soil formation and from this view point they are much younger than soils comprising the bays of higher elevations.

Synopsis

Preliminary studies indicate that landscape features identified as Carolina Bays occur extensively on the Eastern Shore of Virginia. These features appear to be one of the dominant topographic features of the two county area, if not the primary feature. Since Carolina Bays are extensive in the area and vastly different soils have been demonstrated to comprise the various portions of them, it seems pertinent to throughly identify and locate them; to define their physical, chemical, mineralogical, and morphological properties that affect their utilization; to develop soil interpretations for multipurpose usage; and to develop explanations relevant to their origin and possible future disposition.

National and international press releases of a paper on Carolina Bays presented at the Virginia Academy of Science in May, 1973, resulted in widespread inquiry from the scientific community and the general populace for more information on the subject.

A comprehensive investigation of Carolina Bays on the Eastern Shore of Virginia was initiated in June, 1973. Detailed remote sensing evaluations, field studies, and laboratory investigations have been undertaken, and they are well underway. Initial phases of the study will be completed this year.

A very practical role for the direct utilization of remote sensing imagery and methodology has been demonstrated in the study of Carolina Bays. The integration of remote sensing technology as a functional tool in natural resource investigations appears to offer significant utilitarian benefits.

At the present time one M.S. thesis is being completed on the study of Carolina Bays via remote sensing techniques. The study should be completed by June 15, 1974, and a copy of the thesis will be made available to NASA.

REMOTE SENSING OF TIDEWATER RESEARCH AND CONTINUING EDUCATION CENTER

The Tidewater Research and Continuing Education Center is located near Holland, Virginia. The topography of the area is level to gently rolling. The soil type map is given in Fig. 19. A legend of the soil map is given in Table 11. The Research Station is located in the lower Coastal Plain and the area is comprised of sandy, acid soils representative of an intensive agricultural region. Imagery of the Center will permit extension of the soil and crop data base for these outer Coastal Plain portions of the Chesapeake Bay region. Extensive research conducted on peanuts at Holland permits the establishment of spectral characteristics for this important crop under various conditions.

During 1973 three flights were flown over the Center. These are reported in Table 12. Ground truth data were recorded for each flight. The ground truth data included percent soil moisture, soil temperature, type and height of vegetation, percent ground cover, and color of the surface soil. The imagery of the flights for 1973 are being evaluated on a microdensitometer and are being correlated with the ground truth data.

Fig. 20 gives an aerial view of the station using color SO-397 and color IR 2443 film.

Preliminary site analysis details have been made for the installation of a NASA data collection platform (DCP) at the Holland research site. The monitoring station will continuously monitor solar radiation, wind speed and direction, air temperature, and soil temperatures at selected locations. The data will be relayed to NASA-Goddard and subsequently to NASA-Wallops via ERTS 1 satellite. This system permits quick availability of the environmental data and eliminates the chore of obtaining strip-chart data and transposing operations. Establishment of a data base for these environmental

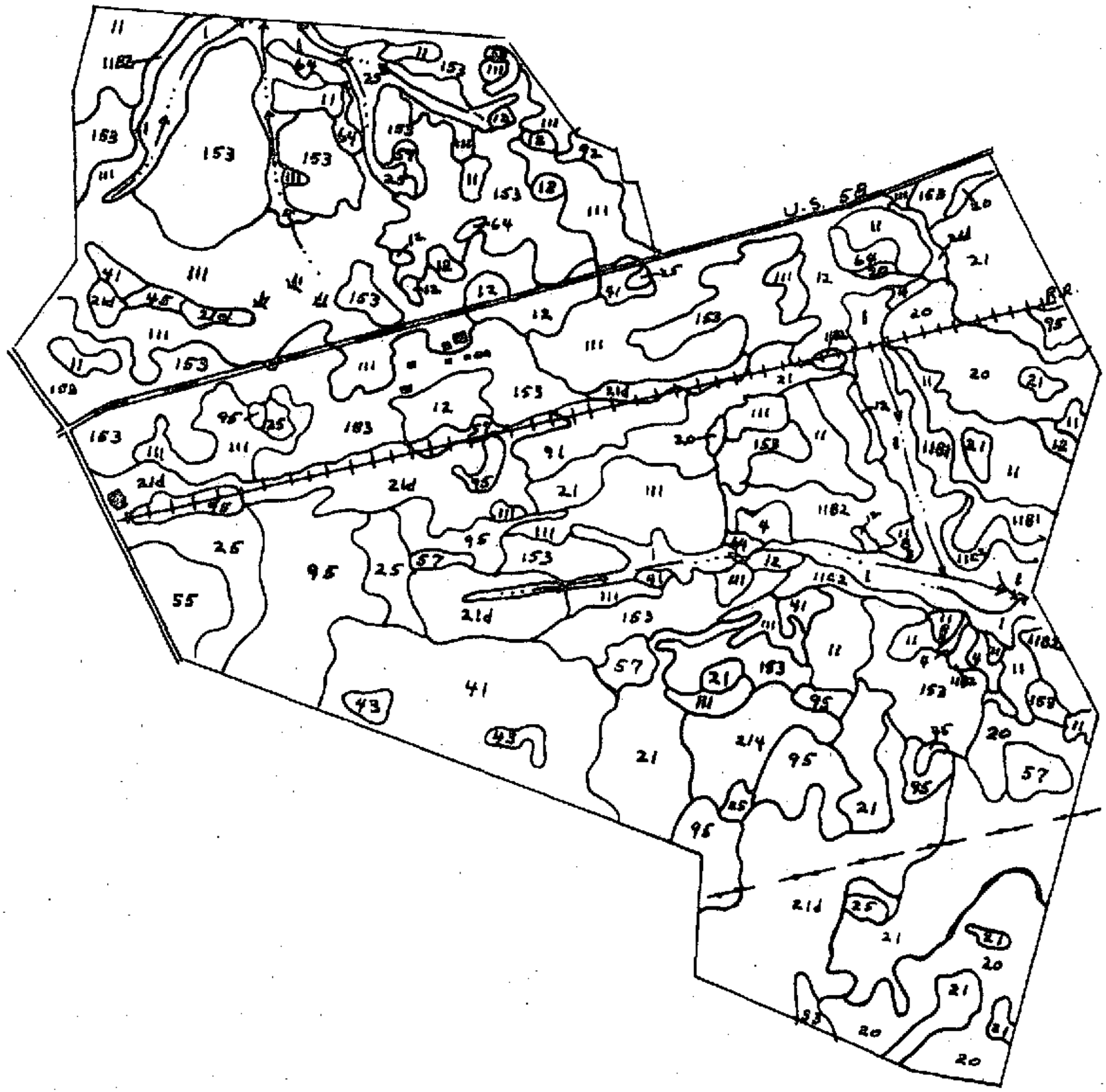

Fig. 19. Soil type map of the Tidewater Research and Continuing Education Center.

Table 11. Soil legend for the Tidewater Research and Continuing Education Center.

1	Mixed local alluvium
4	Alluvial-colluvial loams and silt loams
11	Sassafras loamy fine sand
12	Kloj1/ loamy fine sand
20	Mattapex1/ very fine sandy loam
21	Bertie2/ very fine sandy loam
25	Portsmouth loam
41	Fallsington fine sandy loam
43	Swamp
53	Woodstown fine sandy loam
55	Bayboro silt loam
57	Dragston fine sandy loam
64	Galestown1/ loamy fine sand
91	Othello1/ fine sandy loam
92	Pocomoke loam
95	Othello loam
111	Dragston loamy fine sand
153	Woodstown loamy fine sand

Slope Classes

A - 0-2 percent3/
B - 2-5 percent
C - 5-8 percent
D - 8 percent and over

Erosion Classes

0 No apparent erosion3/
+ Accumulations
1 Slight erosion; less than 25% surface soil removed
2 Moderate erosion; 25-75% surface soil removed

Land Use Classes

L - Cultivated
P - Pasture
X - Idle
F - Woodland
F_1 - Brushland
H - Homestead, urban and miscellaneous

1/ Tentative series

2/ Tentative series, redefined

3/ Class A slope and 0 erosion will not be mapped and will be assumed for all mapping units not carrying slope and erosion designations.

Table 12. Flights flown over the Tidewater Research and Continuing Education Center and imagery data collected.

Date	Time	Imagery	Remarks
5/31/73	1105 EDST	Color S0-397 Color IR 2443	C-54 A/C
7/27/73	1120 EDST	Color S0-397 Color IR 2443	C-54 A/C
9/6/73	1020 EDST	Color S0-397 Color IR 2443	C-54 A/C

factors will permit more intensive correlation of imagery with ground truth parameters. These data will also serve a valuable role in providing environmental information that is not available elsewhere to the agricultural sector. The monitoring station will provide environmental data for the outer fringe of the Chesapeake Bay region which can be correlated with data obtained at the Virginia Truck and Ornamentals Research Station to augment a semi-network for this important agricultural sector.

Fig. 20. Aerial view of the Tidewater Research and Continuing Education Center. Color SO-397 on the left and color IR 2443 on the right (photos taken 9/6/73).

REMOTE SENSING OF EASTERN VIRGINIA RESEARCH STATION, WARSAW, VIRGINIA

The Eastern Virginia Research Station located near Warsaw, Virginia, conducts research on small grains, soybeans, corn, and hay crops such as alfalfa and clover. The topography of the area is level to gently rolling with the slope varying from 0-4%. Soils of the area have been mapped and they are identified in Fig. 21. The area is comprised of sandy, acid Coastal Plain soils that are quite similar to those at the primary research site at the Virginia Truck and Ornamentals Research Station. Imagery of the area permits an extension and refinement of soil and crop spectral characteristics typical of the Chesapeake Bay region.

During 1973 three flights were flown over the research station. These are reported in Table 13. Ground truth data were recorded for each flight. The ground truth data included percent soil moisture, soil temperature, type and height of vegetation, and percent ground cover. The imagery of the flights for 1973 is being evaluated on a microdensitometer and is being correlated with the ground truth data.

An aerial view of the station taken with color SO-397 and color IR 2443 film is given in Fig. 22.

To help define the spectral signature of soybeans with time, flights were flown over two privately owned farms near Warsaw, Virginia. During 1973 three flights were flown over the Blackwell and Hundley farms. These are reported in Table 14. Ground truth data including soil temperature, vegetation type and height, and percent ground cover were recorded. The imagery of the flights is being evaluated on a microdensitometer and is being correlated with ground truth data. The spectral information obtained from these privately owned farms is representative of typical soybean production

SOIL SURVEY
Eastern Virginia Research Station
Warsaw, Virginia
by
J. H. Elder and H. C. Porter
June 1967

Soil Legend

1A1 - Sassafras fsl. (thick solum variant), 0-2% slope
1B1 - Sassafras fsl., 2-4% slopes
2A1 - Sassafras fsl. (concretionary substrata), 0-2% slopes
3A1 - Sassafras loam, 0-2% slope (colluvial variant)
4A1 - Sassafras sandy loam, 0-2% slopes
5B1 - Rumford fsl. 2-4% slopes
6A1 - Kempsville fsl. (heavy subsoil variant, 0-2% slopes)

Symbols

1A1 - Soil No. slope and erosion
Soil Boundary
Property and plot Boundaries
Drainage ways
S - Small spots of moderate sheet erosion

(Pan) Small area with pan horizon in subsoil

Soil names subject to change

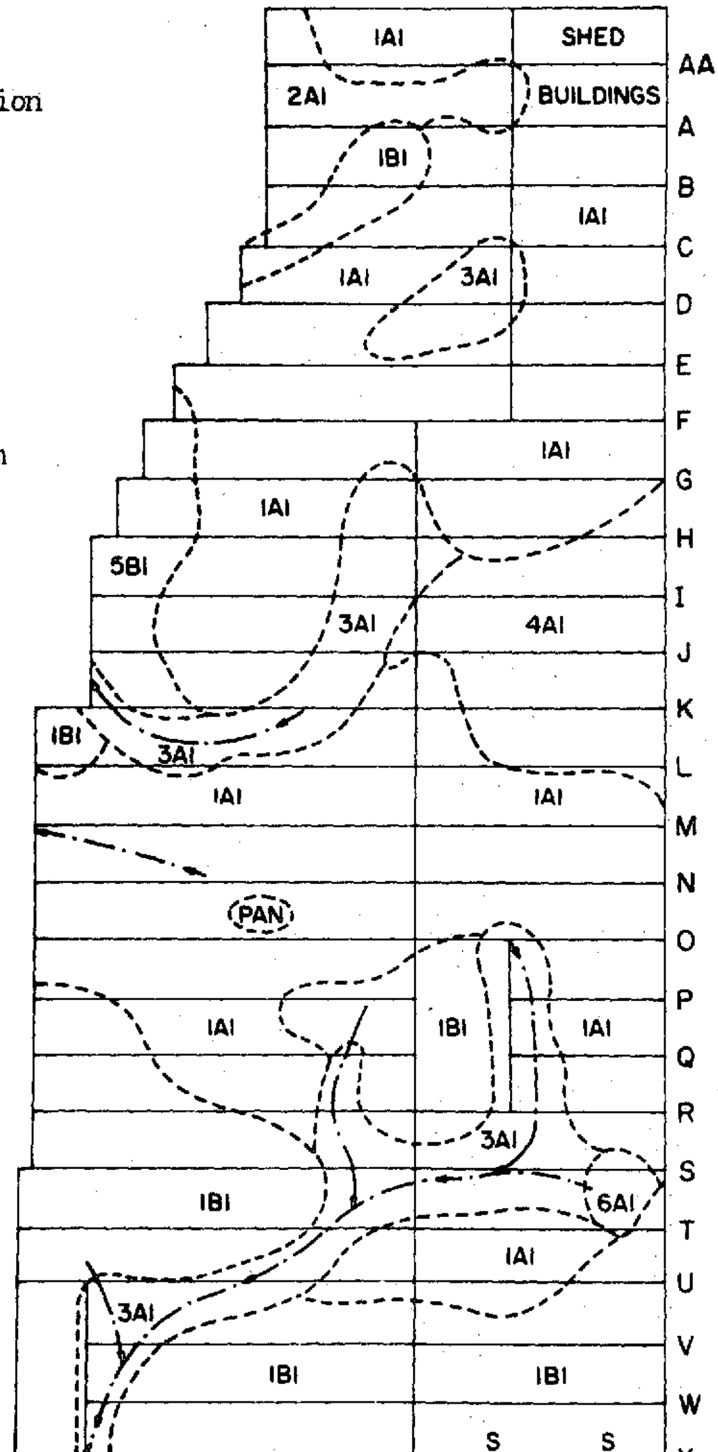

Fig. 21. Soil type map of the Eastern Virginia Research Station, Warsaw, Virginia.

Table 13. Flights flown over the Eastern Virginia Research Station and imagery data collected.

Date	Time	Imagery	Remarks
5/31/73	1223	Color S0-397 Color IR 2443	C-54 A/C
7/16/73	1415	Color S0-397 Color IR 2443	C-54 A/C
9/6/73	1130	Color S0-397 Color IR 2443	C-54 A/C

Table 14. Flights flown over the Blackwell and Hundley farms and imagery data collected

Date	Time	Imagery	Remarks
		Blackwell Farm	
5/31/73	1155	Color S0-397 Color IR 2443	C-54 A/C
7/16/73	1355	Color S0-397 Color IR 2443	C-54 A/C
9/6/73	1225	Color S0-397 Color IR 2443	C-54 A/C
		Hundley Farm	
5/31/73	1135	Color S0-397 Color IR 2443	C-54 A/C
7/16/73	1415	Color S0-397 Color IR 2443	C-54 A/C
9/6/73	1145	Color S0-397 Color IR 2443	C-54 A/C

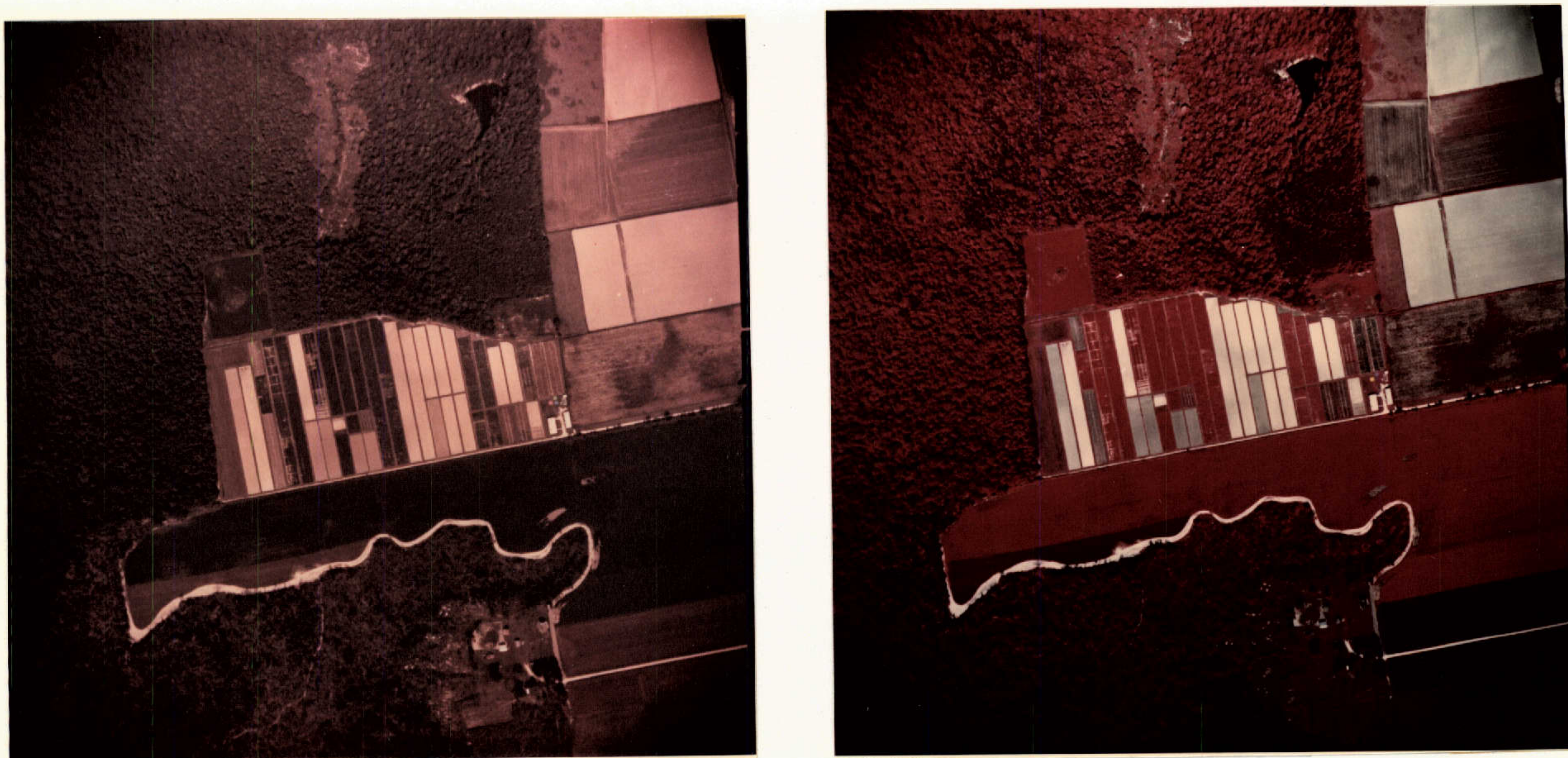

Fig. 22. Aerial view of the Eastern Virginia Research Station, Warsaw, Virginia. Color SO-397 on the left and color IR 2443 on the right (photos taken 9/6/73).

systems in the Chesapeake Bay region. Data can be integrated with findings from the research stations to produce a comprehensive model.

An aerial view of the Blackwell farm taken with color S0-397 and color IR 2443 film is given in Fig. 23.

An aerial view of the Hundley farm taken with color S0-397 and color IR 2443 film is given in Fig. 24.

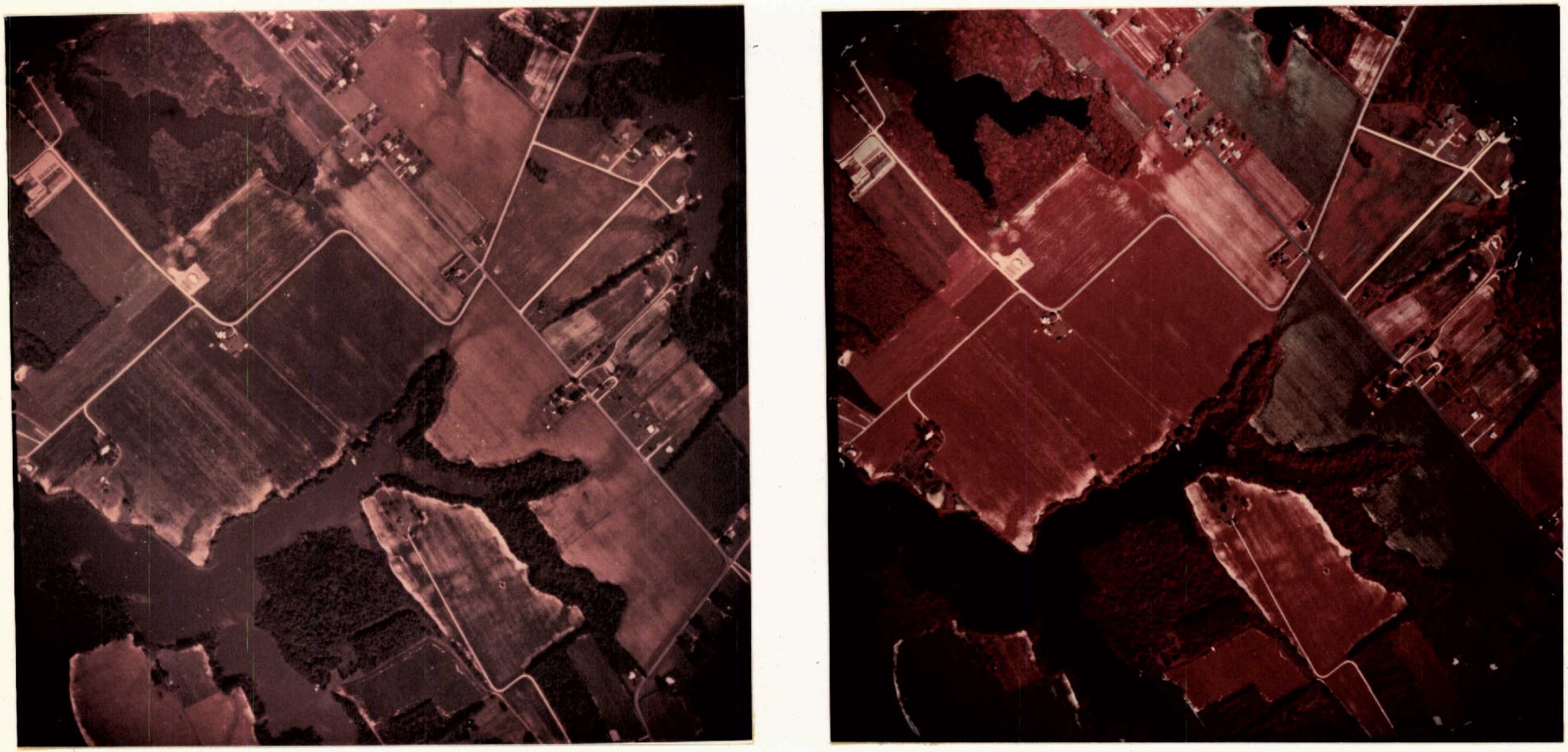

Fig. 23. Aerial view of the Blackwell farm near Warsaw, Virginia. Color SO-397 on the left and color IR 2443 on the right (photos taken 9/6/73).

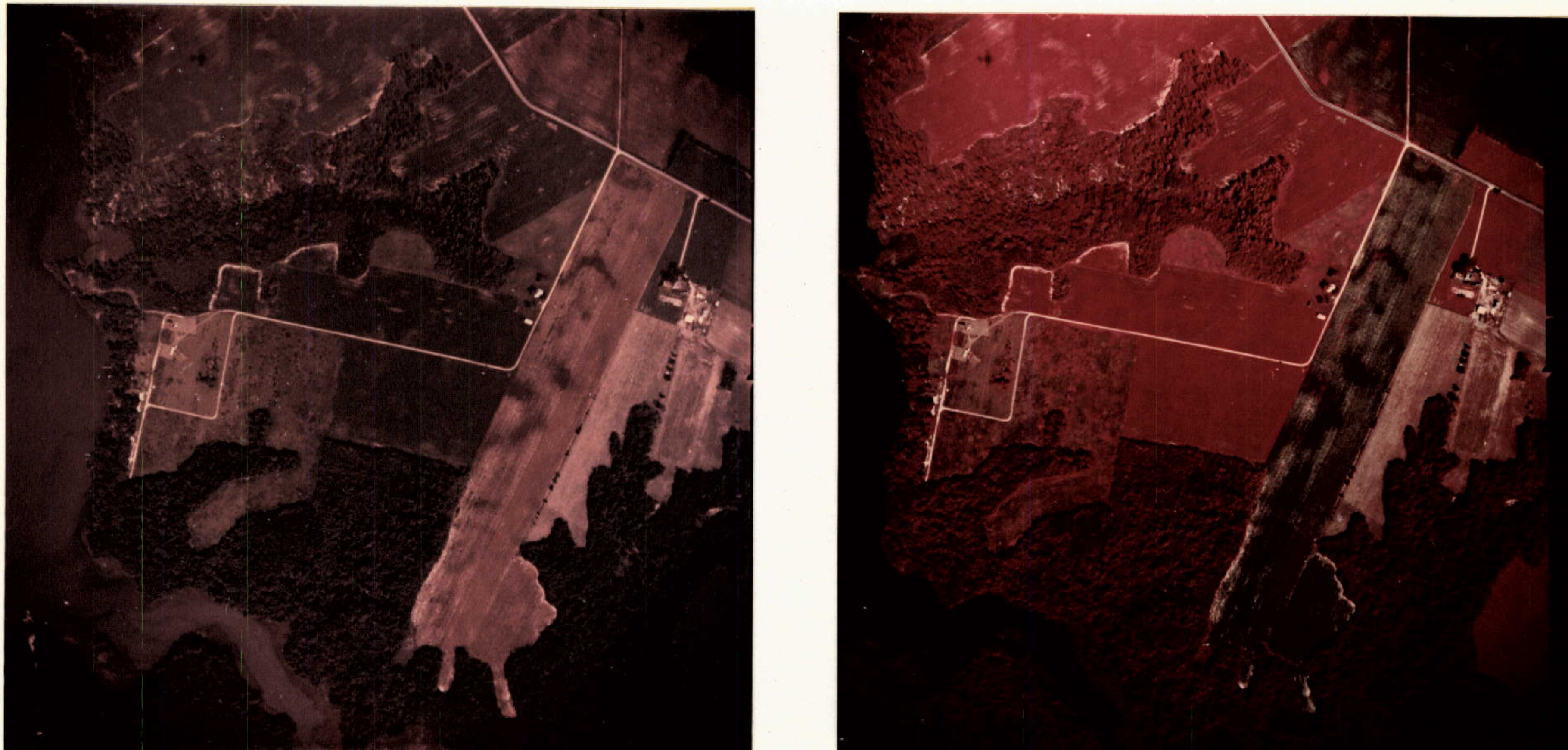

Fig. 24. Aerial view of the Hundley farm near Warsaw, Virginia. Color SO-397 on the left and color IR 2443 on the right (photos taken 9/6/73).

REMOTE SENSING OF CYLINDROCLADIUM BLACK ROT DISEASE OF PEANUTS

Cylindrocladium black rot disease of peanuts has occurred in six major peanut producing counties in Virginia. At several locations, this disease has killed 70 to 90% of the plants within the infested area. The disease is caused by a soil borne fungus that invades the root tip and progresses through the root system. In advanced stages, the disease causes a black rot of peanut roots and pods and the vine dies.

To help develop a spectral signature of peanuts infested with *Cylindrocladium* black rot disease, one flight was flown over research plots established by the Department of Plant Pathology and Physiology of Virginia Polytechnic Institute and State University. The plots were located on the W. C. Knight farm near Suffolk in Nansemond County, Virginia. The flight was flown at approximately 500 and 1000 feet at 1420 EDT, September 18, 1973. Imagery obtained included both color SO-397 and color IR 2443 positive transparencies of the infested areas.

The imagery data is being analyzed with the microdensitometer and is being correlated with ground truth data of the area. The ground truth data was recorded for the area on the same date of the flight. Initial observation of the imagery indicates dramatic differences in tonal patterns exist between healthy and diseased peanuts. It appears the resolution obtained in the lower altitude imagery may permit detection and evaluation of single plants. Using the imagery to select tentative infestation areas subsequent field examinations revealed that a much higher degree of accuracy could be obtained in measuring degree of infestation from the color infrared photographs than actual field observations.

An aerial view of part of the infested area (color IR taken at 500 feet and color IR taken at 1000 feet) is given in Fig. 25.

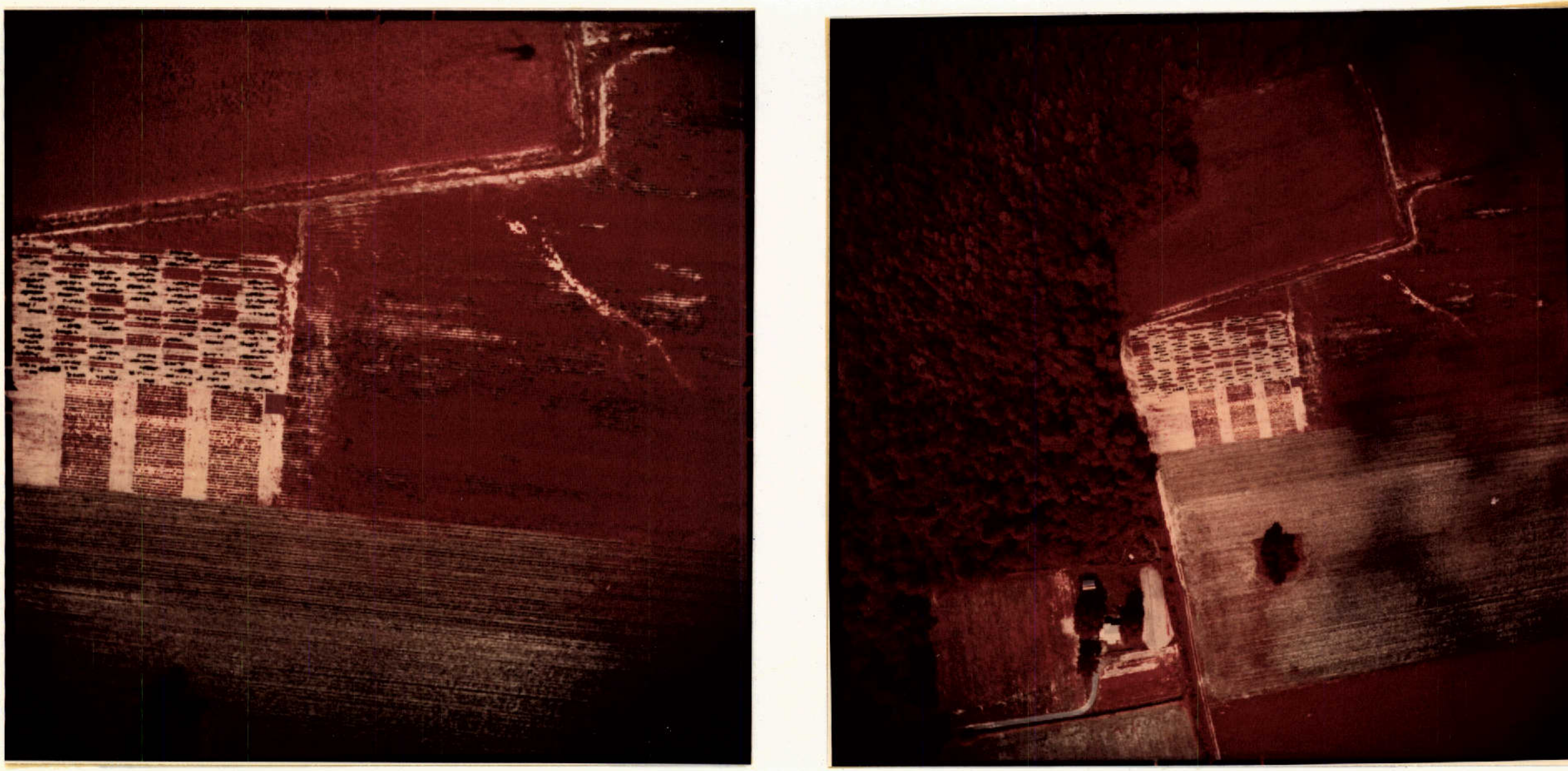

Fig. 25. Aerial view (color IR) of the plots of Cylindrocladium black rot disease of peanuts near Suffolk, Virginia. Photo on left taken at 500' and on right taken at 1,000'. (Photos taken 9/18/73)

The occurrence of cylindrocladium black root disease in peanuts has created grave concern among producers and research scientists. The potential wide spread infestation of the peanut crop poses a severe economic threat to a rather large segment of the agronomic economy of Virginia and North Carolina. The absence of effective control measures for the disease and lack of an effective disease detection system tend to make the problem more severe. The use of remote sensing technology to detect and record the occurrence and spread of the disease offers considerable promise.

This study is incomplete. Work will continue throughout the 1974 growing season. A series of flights will be flown over test sites to determine if remote sensing can detect the difference in sick and healthy plants in the very early stages of the disease.

REMOTE SENSING OF UNIVERSITY OF DELAWARE SOIL FERTILITY DEMONSTRATION PLOTS

During 1972 and 1973 four flights were flown over the University of Delaware soil fertility demonstration plots at Millsboro, Delaware. The cooperative study with the University of Delaware interfaced the developed remote sensing methodology of the project with a continuing research effort conducted by Dr. M. Teel of the Agronomy Department of the University of Delaware in a practical utilization of remote sensing technology. Fertility inbalances resulting in reduced crop yield of corn and possibly soybeans are being investigated in the continuing program. The dates of the flights and the imagery obtained are given in Table 15. Ground truth data collected by University of Delaware personnel included soil moisture, type of vegetation, and fertility applications. During the July 26, 1973, flight a few chlorophyll extractions from leaves were taken.

The soil fertility demonstration plots consists of two sections with 72 plots in each section. Each section is nine plots long and eight plots wide with a fifteen foot border strip between each section. An aerial view of the plots is given in Fig. 26 (color SO-397 and color IR 2443 film).

Imagery obtained during three overflights (8/29, 7/31, 9/11/72) of the test plots near Millsboro, Delaware, were analyzed via the scanning micro-densitometer at NASA-Wallops Island. The 9-1/2" positive transparencies were placed on the rotating drum of the microdensitometer and coordinates were obtained of the specific area of the photograph to be scanned. The coordinate data was programed into the mini-type computer which controls the micro-densitometer. The resultant optical density output data from the microdensito-meter was stored on magnetic tape for computer analyses in the NASA-Wallops

Table 15. Flights flown over the University of Delaware soil fertility demonstration plots and imagery data collected.

Date	Time	Imagery	Remarks
7/31/72	1352	Color S0-397 Color IR 2443	C-54 A/C
9/29/72	1051	Color S0-397 Color IR 2443	C-54 A/C
9/11/72	1325	Color S0-397 Color IR 2443	C-54 A/C
7/26/73	1130	Color S0-397 Color IR 2443	Helo.

Island computer system. The microdensitometer at Wallops permits the density values for a particular scan to be divided into 256 density levels. The computer then groups these 256 density levels into 14 units which are utilized for gray scale printouts. These 14 density classes are based on the density range of the area and not on the total range capacity of the scanner (0-3.00).

Natural color and color IR photographs obtained July 31, August 29, and September 11, 1972, of the corn and soybean plots were selected for analysis on the microdensitometer. No filters were utilized on the microdensitometer with the color photographs. However, in order to evaluate the color separation, a red, green, and blue filter was employed with the color infrared imagery of August 29 on the microdensitometer.

The computer gray scale maps are mirror images of the photographs due to the computer program. The gray scale maps were analyzed by locating areas

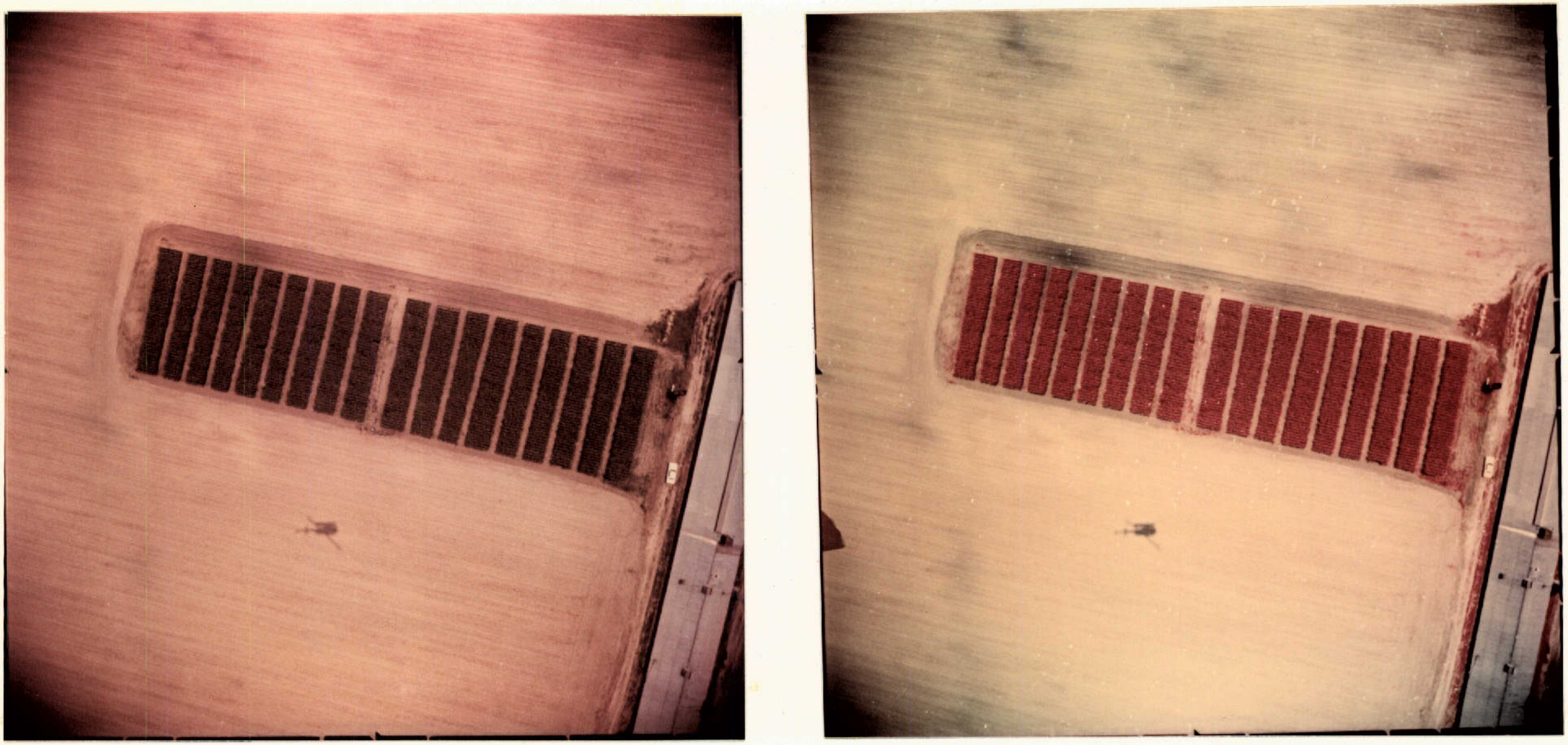

Fig. 26. Aerial view of the University of Delaware soil fertility demonstration plots near Millsboro, Delaware. Color SO-397 on the left and color IR 2443 on the right (photos taken 7/26/73).

representing specific agricultural features, drawing rectangular areas encompassing representative areas and comprised of 50 to 100 computer symbols, identifying and counting each symbol in the rectangle, and multiplying the number of each symbol by the average optical density that is represented. Summation of these density values for each rectangle produced the average density for this area. Four rectangles were calculated for each feature on each gray scale map. Values were very consistent.

Observations

Due to the skewness of the gray scale maps and the small plot size, it was very difficult to accurately locate and delineate the test plot boundaries. However, small plot areas (10 x 20 feet) have been analyzed in other studies where contrasting surrounding borders occur.

The results (Table 16) of the color photograph microdensitometer data indicated the wet areas of the corn plots were easily distinguishable. The wet areas had density values averaging 2.02 compared to values of 2.29. This magnitude of density variation is generally significant at the 99% level. Soybeans did not exhibit much variation in the measured optical density values without the color separation.

The analyses of the color infrared photograph of August 29 was very dependent on the filter used, but generally much better discrimination was obtained with it than the natural color photo of the same date. Use of the clear filter resulted in a fair degree of separation between soybeans, normal corn, and the wet area of corn. Best results were obtained in discrimination of the corn and soybeans by using a red filter. Soybeans (density of 1.37) were easily separated from any corn area (density

Table 16. Average density values for several agricultural variables at various dates in 1972, utilizing various film-filter combinations.

Date	Film Type and Filter		Panels					Corn			Soybeans	Comments
			Wt.	Gr. 1	Gr. 2	Gr. 3	Black	Normal	Wet Areas	Plot 14		
8/29/72	Color IR -	Clear	0.00-1.84	0.00-1.84	0.00-1.84	2.52	2.58-3.00	2.39	2.20	ND	2.09	Fair Separation
		Red	0.00-1.28	1.33	2.22-3.00	2.22-3.00	2.22 3.00	1.78	1.50	2.05	1.37	Execellent Separation
		Green	0.00-2.28	0.00-2.28	0.00-2.28	ND (1)	ND	2.85	ND	ND	2.74	Too dark
		Blue	0.00-1.69	0.00-1.69	0.00-1.69	ND	ND	2.65	ND	ND	2.56	Too dark
8/29/72	Color	Clear	0.00-1.76	0.00-1.76	0.00-1.76	1.75	2.23	2.18	2.13	ND	2.12	
7/31/72	Color	Clear			NO PANELS			2.29	2.02	ND	2.27	
9/11/72	Color	Clear	----------	----------	----------	----------	----------	2.19	ND	1.90	2.17	Soybeans impossible to separate even from corn

(1) Not Detectable

1.50-2.05). The wet area of corn (density 1.50) was readily separated from the normal corn area within the test plots. An area near plot 14 was also detectable, and it appeared much darker (density 2.05). Use of the green and blue filters resulted in less ability to separate soybeans and corn.

Difficulty was encountered with analyses of the September 11 imagery in attempting to separate crops on the basis of optical densities. However, a large area near plot 14 appeared as a lower density level (1.90 suggesting reduced corn stand.

A synopsis of the results of the 1972 flights include:

1. Skewness and small plot size made it difficult to locate individual plots on the gray scale maps with a degree of accuracy.
2. Soybeans could be readily separated from corn using color infrared photographs without a filter purely on the basis of optical values for the August 29 flight. The wet area of the corn plot was also clearly distinguishable.
3. The red filter in combination with color infrared appeared to be optimum for maximum discrimination.

The imagery data collected on July 26, 1973, is being evaluated by microdensitometer and the results are being correlated with the ground truth data.

REMOTE SENSING OF UNIVERSITY OF MARYLAND RESEARCH STATION, SALISBURY, MARYLAND

On July 26, 1973, a flight was flown over the University of Maryland Research Station near Salisbury, Maryland. Imagery data obtained included both color S0-397 and color IR 2443. This data was made available to the personnel at the research station for their use. Fig. 27 gives an aerial view of the station (color S0-397 and color IR 2443).

The Salisbury station is located on Coastal Plain soils similar to the Virginia Truck and Ornamentals Research Station. The imagery obtained at Salisbury enabled a data base extension for both soils and various crops to a broader area of the Chesapeake Bay region.

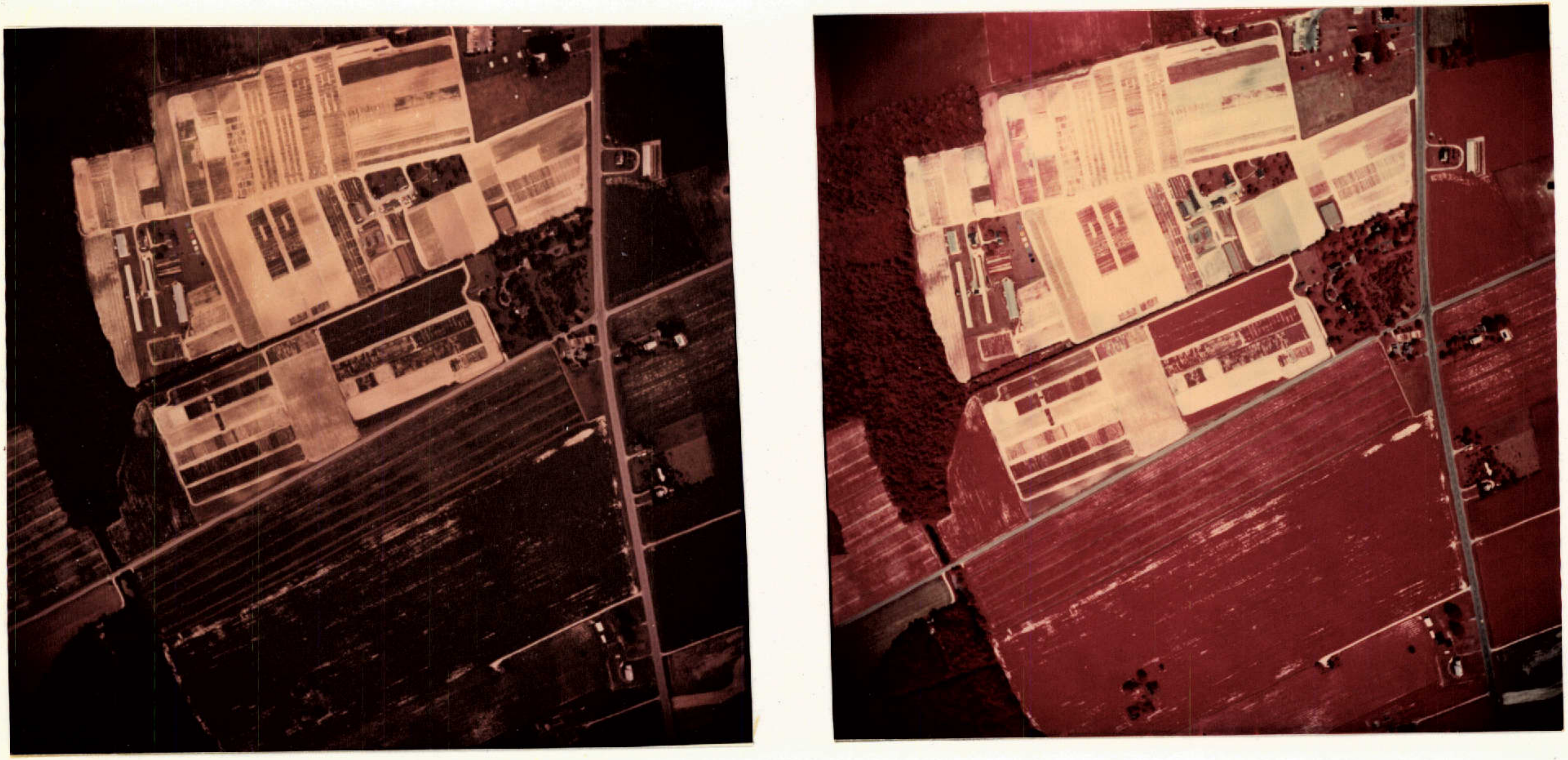

Fig. 27. Aerial view of the University of Maryland Research Station, Salisbury, Maryland. Color SO-397 is on the left and color IR 2443 is on the right (photos taken 7/26/73).

REMOTE SENSING OF THE SOUTHERN PIEDMONT RESEARCH AND CONTINUING EDUCATION CENTER

Nature of Site

The Southern Piedmont Research and Continuing Education Center is located at Camp Picket approximately one mile east of Blackstone, Virginia, in southeastern Nottoway County. The Research Station comprises approximately 1130 acres in the gently sloping topography of the southern Piedmont. The developing multi-purpose agricultural research station will integrate research agricultural activities for the region, combining activities previously conducted at other locations. Agriculture is a major industry in the 21 county region comprising the Southern Piedmont. Approximately 27,500 farms in the region produced $133 million of products in 1964 which accounted for about 28 percent of the cash farm income in Virginia.

The remote sensing overflight presented a unique opportunity to photographically document a native, wooded tract of land which will be developed into a multi-purpose research station. The study also represents a practical utilization and demonstration of remote sensing methodology in agriculture. Not only will the imagery serve as a valuable documentary of native conditions at the site, but also as a base map for detection of various soil, vegetation, surface drainage, and cultural conditions that currently exist, and also serve as a valuable tool to aid in the planning and development sequence of the station.

Methods

A special remote sensing overflight of the research station was conducted on December 11, 1972. The NASA-Wallops Island C-54 aircraft was utilized as an aerial platform to obtain color (SO-397), and color-infrared (2443) imagery.

The overflight was made near noon under very cloudy, overcast conditions. During the photographic passes the sun intermittently broke through the overcast contributing to variation in the imagery. Color panels were displayed for the flight and representative temperature, soil moisture, and soil conditions were measured during the mission. A soil map of the Station is presented in Fig. 28 and the legend for the map in Table 17.

Preliminary Evaluation

The imagery obtained was marginal for detailed, photographic evaluations due to overcast conditions during the flight. Considerable tonal variation occurred on adjacent photographs primarily due to fluctuating light conditions created by intermittent breaks in the cloud cover. However, the imagery was satisfactory for basic evaluations relating to present land use, surface drainage, vegetation type distribution patterns, cultural disturbance patterns, and various soil conditions.

The flight date had been selected for a period when the trees had lost their leaves in order to penetrate the forest canopy to analyze soil conditions, and to enhance photographic differences between coniferous and deciduous vegetation. Generally, photographic delineation of the coniferous species was possible, and soil conditions under the forest canopy were evident. Elevation of the area ranged from 350 to 430 feet above sea level and the surface drainage systems were clearly detectable.

Radiation measurements of the color panels are presented in Table 18, which indicate a range of 3°C for the panels. Radiation data on representative surface features (Table 19) reveal a marked spread among the features.

Interpretation of the imagery is continuing in conjunction with the various development phases of the station.

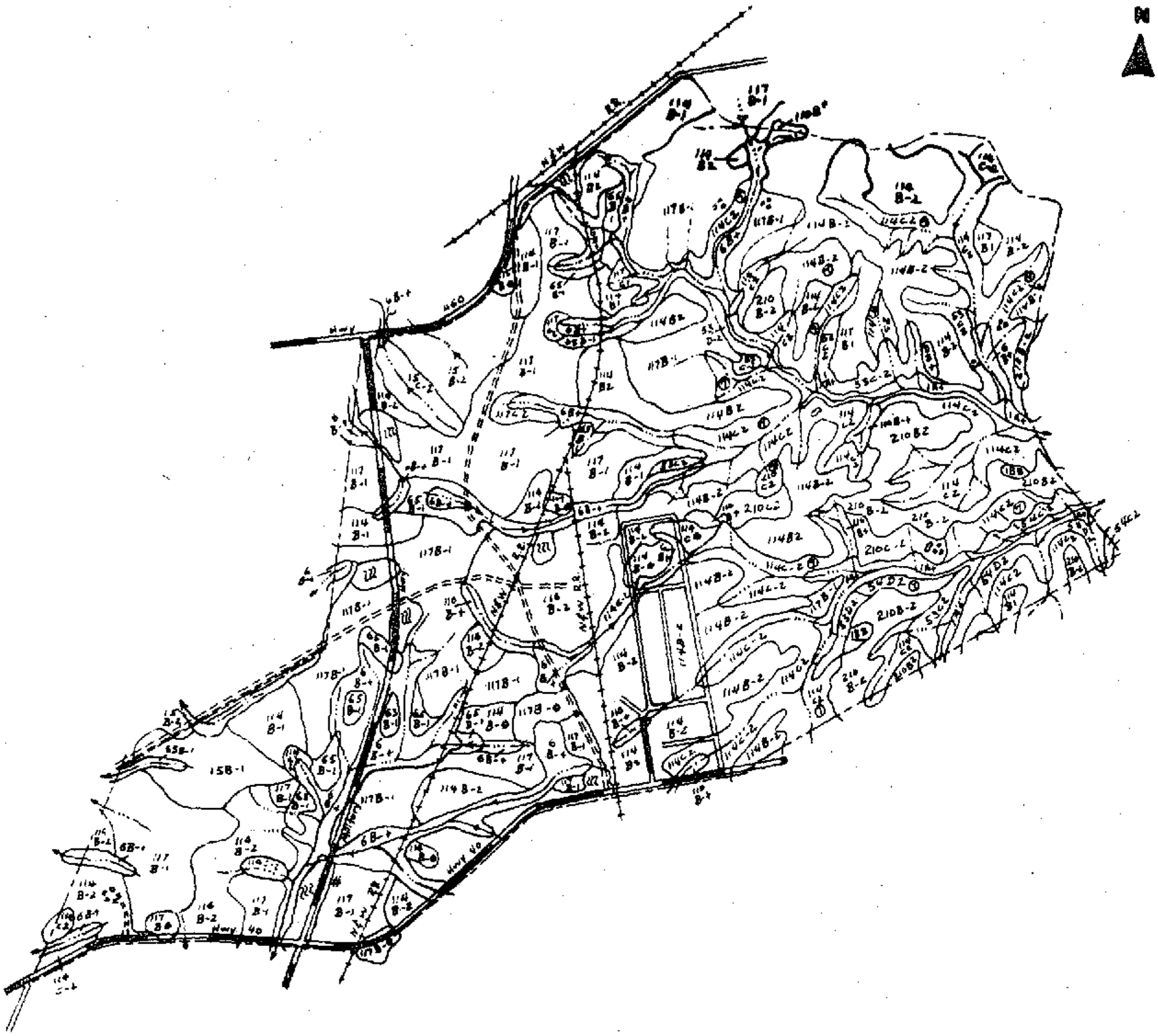

Fig. 28. Soil map of the Southern Piedmont Research and Continuing Education Center, Blackstone, Virginia.

Table 17. Soil legend of the Southern Piedmont Research and Continuing Education Center.

Map Symbol	Soil Name
114 B-1	Appling coarse sandy loam
117 B-1	Durham coarse sandy loam
110 B+	Seneca sandy loam
114 B-2	Appling coarse sandy loam
65 B1	Colfax sandy loam
6 B+	Worsham sandy loam
114 C2	Appling coarse sandy loam
15 Bθ	Appling fine sandy loam
65 B-1	Colfax sandy loam
117 C-1	Durham colfax sandy loam
117 C-2	Durham coarse sandy loam
53 D-2	Louisburg sandy loam
210 B-2	Cecil coarse sandy loam
53 C-2	Louisburg sandy loam
15 C-2	Appling fine sandy loam
15 B-2	Appling fine sandy loam
8 B+	Star loam
210 C-2	Cecil coarse sandy loam
1 A+	Mixed alluvium
117 Bθ	Durham coarse sandy loam
18 B	Stony land
114Bθ	Appling coarse sandy loam
114 Cθ	Appling coarse sandy loam
54 C2	Wilkes sandy loam
54 D2	Wilkes sandy loam
63 B1	Roanoke silt loam
15 B1	Appling fine sandy loam

Slope Groups

A - 0 to 2 percent
B - 2 to 7 percent
C - 7 to 12 percent
D - 12 to 20 percent
E - Over 20 percent

Erosion Symbols

† Recent accumulations
1 Little or no erosion (less than 25 percent of the topsoil removed)
2 Moderate sheet erosion (from 25 to 75 percent of the topsoil removed)
3 Severe sheet erosion (over 75 percent of the topsoil removed)
*0 Borrow areas

Gully Erosion

(7) Occasional deep gullies
(8) Numerous deep gullies
(9) Severely gullied areas

Table 18. Radiation measurements of color panels displayed for the overflight of the Southern Piedmont Research and Continuing Education Center at 11:30 a.m., December 11, 1972.

Color Panel	Temperature (C°)
White	12.5
75% white	18.0
50% white	18.5
25% white	18.5
Black	20.0
Red	14.5
Green	17.5
Blue	17.0

Table 19. Radiation measurements of representative surface features of the Southern Piedmont Research Station at 11:45 a.m., December 11, 1972.

Object	Temperature (C°)
Green Grass	12.0
White Concrete	13.0
Gravel Road	9.0
Macadam Road	13.0
Eroded Soil	9.5

Fig. 29 gives an aerial view of part of the research station (color SO-397 and color IR 2443). Part of the research station is located in the upper half of the figure. The color panels are located near the temporary headquarters building at the airfield on Camp Pickett.

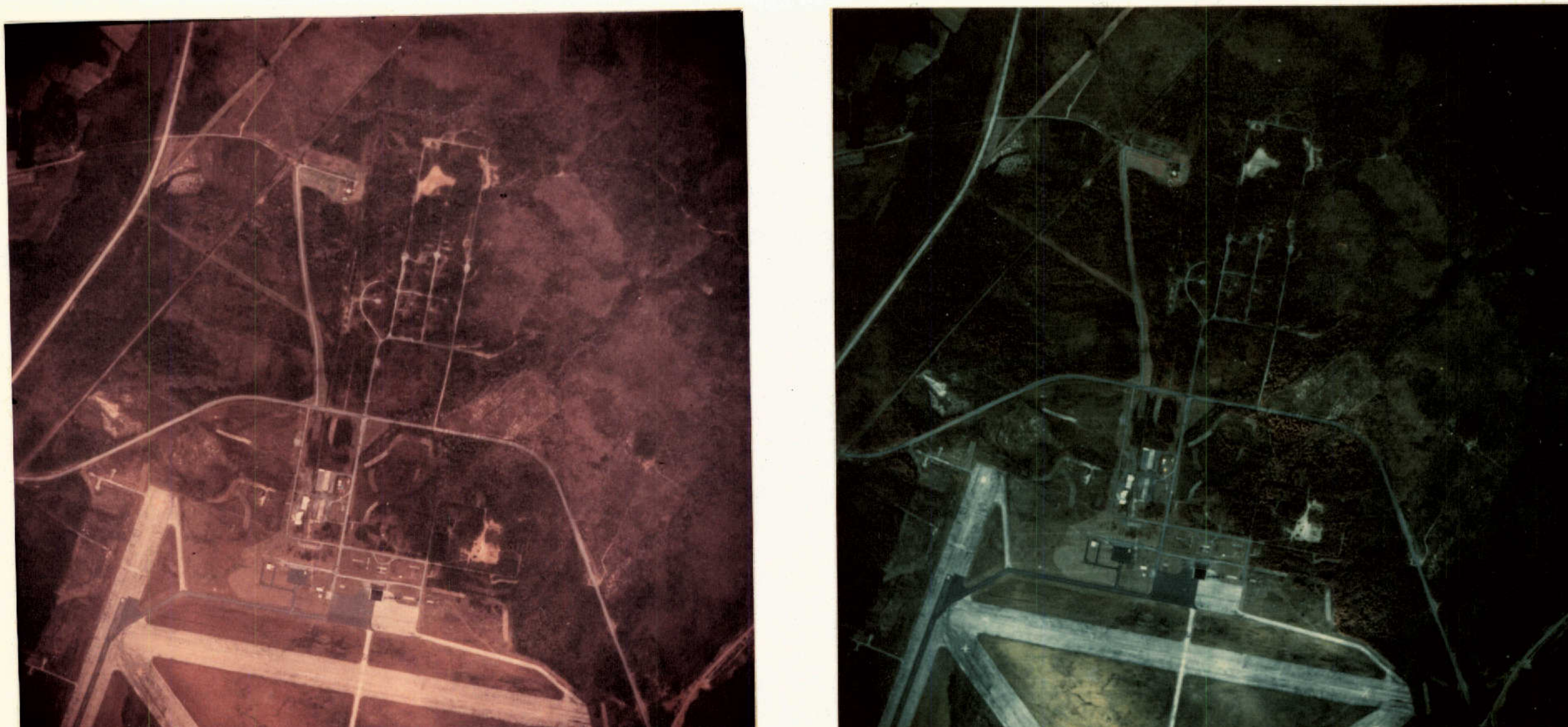

Fig. 29. Aerial view of part of the Southern Piedmont Research and Continuing Education Center. Color SO-397 on the left and color IR 2443 on the right (photos taken 12/11/72).

SUMMARY AND CONCLUSIONS

A review of the literature dealing with remote sensing related to agriculture revealed that most of the related literature was no more than five years old. Comparatively little research involving agricultural remote sensing had been conducted in the humid eastern Coastal Plain section of the United States. Factors affecting multispectral photography and thermal infrared recordings related to the energy reflection of plants and soils have been studied. Remote sensing techniques have been refined for crop, tree species, and soil identification. The detection of plant diseases, insect and pollution damage has also been studied.

From August 1969 through September 1973 twenty-nine remote sensing flights have been flown over the Virginia Truck and Ornamentals Research Station at Painter, Virginia. Ground truth data of the site were collected during each flight. Imagery data collected included black and white infrared, color infrared, and color photographs. Soils on the research station were evaluated and a detailed soil map was prepared. A forest type map was prepared for the wooded area surrounding the research station. An environmental monitoring station was set up to measure soil temperature, air temperature (wet and dry bulb), wind speed and direction, and solar radiation. The information from this monitoring station permits relationship between environmental factors and image quality of remote sensing overflights to be established.

Before detailed analyses of photographic images can be made, it is necessary to obtain photographs with uniform exposure across the fram and between various frames on the same roll of film. Uniform development of the photograph across a single frame can be achieved by the addition of a density filter to the camera system. Obtaining rolls of film with uniformity in color and tones between frames is more difficult. Our results indicate that flight lines should be flown perpendicular to the sun to obtain imagery with minimum color shift between frames.

In a study of the effects of soil moisture and organic matter on the reflection of Sassafras soils at 650 and 900 millimicrons, it was found that the reflection of visible and infrared radiation from Sassafras fine sandy loam was strongly dependent on both moisture and organic matter content. Percent soil moisture variation from field capacity to oven drying caused an increase in percent reflection of 20 to 25% for both wavelengths and various organic matter levels. This increase in percent reflection is an approximate 100% change in total reflection for the sample with 3.0% organic matter. Therefore, failure to consider soil moisture levels could possibly mean an error of at least 100% in attempting to evaluate soil conditions from color or tones of aerial photographs.

An attempt was made at discrimination of forest types utilizing scanner data. Classification of the training areas composed almost entirely of pines gave poor results. Skewness of the flight lines and the small sizes of the training areas may have contributed to the low classification accuracy.

A greenhouse experiment was conducted to determine the effects of fertilizer deficiencies and drought on the chlorophyll content and reflection of Irish potatoes grown in the greenhouse. A complementary field study was conducted to determine the effects of chlorophyll content and reflection on color infrared photographs of field grown Irish potatoes. Data suggest that in order to obtain reflection variations (in the photographic region of the spectrum) between potato leaves with significantly different chlorophyll contents from different plants, it is necessary to subject these plants to fertilizer and drought treatments during initial leaf development. Failure to apply the treatments during initial leaf development may result in leaves with similar leaf structure and reflection characteristics.

Photographic evaluations indicate that high leaf area indices (normally found for most crop species) will produce similar reflection patterns on photographs regardless of the reflection of the uppermost layer of leaves. Therefore, color film which is sensitive only to the uppermost leaf layer might be advantageous in detecting chlorotic conditions.

A very practical role for the direct utilization of remote sensing imagery and methodology has been demonstrated in the study of Carolina Bays. Preliminary studies indicate that landscape features identified as Carolina Bays occur extensively on the Eastern Shore of Virginia, and they appear to be one of the dominant topographic features. Remote sensing techniques show considerable promise for terrainal analyses of soil geographical features.

Beginning in 1972, developed methodology and parameters were extended to broader areas of the Chesapeake Bay region in remote sensing flights to expand the data base and areas of future applications. These areas include the Virginia Truck and Ornamentals Research Station at Painter, Virginia, the Tidewater Research and Continuing Education Center at Holland, Virginia, and the Eastern Virginia Research Station at Warsaw, Virginia, as primary test sites. Other test sites where flights were flown and data collected are the Hundley and Blackwell farms near Warsaw, Virginia, the peanut *Cylindrocladium* black rot disease plots near Suffolk, Virginia, the University of Delaware soil fertility demonstration plots near Millsboro, Delaware, the University of Maryland Research Station near Salisbury, Maryland, and the Southern Piedmont Research and Continuing Education

Center at Blackstone, Virginia. A description of each test site and the research being conducted at each location are discussed in this report. In addition to gaining knowledge over a broader data base important breakthroughs were made in educating and involving various researchers, agriculturalists, goverment officials and others of the multi-state Chesapeake Bay region in practical uses of remote sensing technology on a functional basis.

Preliminary site analysis details have been made for the installation of a NASA data collection platform at the Tidewater Research and Continuing Education Center. The monitoring station will monitor solar radiation, wind speed and direction, air temperatures, and soil temperature at selected locations to provide a valuable data base that is not currently available in the area.

The imagery data collected in 1973 at all test sites is being evaluated by microdensitometer and the results are being correlated with the ground truth data.

Progress achieved in this project has resulted in the development of functional remote sensing techniques and established basic data parameters for soil and plant conditions of the region. Basic remote sensing-soil-plant interaction relationships have been determined. Practical systems have been developed to evaluate imagery, collect relevant ground truth data, and manipulate and interpret data on an operational basis. Practical applications of remote sensing technologies have been demonstrated to a broad sector of the Chesapeake Bay region.

RECOMMENDATIONS

Using knowledge gained in essential subject areas during the first three years of this project, the following recommendations for further study are given:

(1) Maintain 3 to 5 remote sensing flights of soils and crops during various growth and seasonal stages at the Virginia Truck and Ornamentals Research Station, the Tidewater Research and Continuing Education Center, and the Eastern Virginia Research Station during the 1974-75 growing seasons to obtain a sufficient data base of the Chesapeake Bay Region.

(2) Make periodic overflights of the Southern Piedmont Research and Continuing Education Center to monitor changes occurring during the development of the research station from a natural wooded area.

(3) Continue pre-visual detection studies of specific crops for plant stress and disease infestation.

(4) Intensify evaluations and data processing of obtained imagery to amplify "spectral signature" data bases for specific crop and soil conditions. Refine training classes and accentuate data processing techniques.

(5) Develop interface between photographic imagery and non-photographic data. Evaluate photographic imagery analysis techniques relevant to specific plant-soil "spectral signatures".

(6) Integrate various experiments underway at the experiment stations being monitored to evaluate the use of remote sensing data as a functional part of the total research documentation approach in agronomic sciences.

(7) Accentuate the development of an environmental monitoring network of the agronomic sectors of Chesapeake Bay region relevant to remote sensing technology via usage of Data Collection Platforms (DCP) and ERTS satellite systems.

(8) Compare and evaluate ERTS, U-2, and Skylab imagery for the identification of specific soil and crops in the region.

(9) Utilize mobile spectrophotometer equipment to augment spectral responses for specific plants under varying conditions.

(10) Extend obtained data recognition classes to practical land use classification areas.

(11) Extend research findings to the agronomic sectors as a functional tool. Publish significant findings.

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APPENDIX A

Soil Description Virginia Truck and Ornamentals Research Station

1A1 - Sassafras fine sandy loam, 0-2% slopes is a deep, well drained soil that has formed in moderately coarse textured marine sediments of the lower Coastal Plains. This soil comprises a small acreage in the eastern and north central part of the farm. Surface runoff is slow and internal drainage is moderate to rapid. Base saturation in and below the solum is usually less than 35% where soil has not been heavy fertilized or limed. Heavily limed and fertilized acres may have base saturation above 35% because of good permeability of the surface and subsoil.

Following is a description of Sassafras fine sandy loam taken on a low lying ridge in the south eastern edge of the farm.

Ap	0-8"	Brown (10YR 4/3 to 5/3) very friable to nearly loose fine sandy loam.
A2 or A3	8-13"	Brownish yellow (10YR 4/6) faintly mottled with light yellowish brown and very pale brown, slightly firm, slightly brittle, slightly compact, fine sandy loam. This horizon has formed by illuviation of finer materials from the plow layer and has been called an arena pan in places. It has weak fine subangular blocky, to very weak medium platy structure in places, but crushes readily to fine granular or single grain structure.

B2t	13-25"	Strong brown (7.5YR 5/6) friable slightly sticky, slightly plastic, light fine sandy clay loam, weak fine and medium subangular blocky structure; clear smooth boundary, few faint clay film and bridging of clay between soil particles.
B3	25-31"	Strong brown (7.5YR 5/4 to 5/6) friable very slightly sticky loamy fine sand; very weak medium subangular blocky structure that crushes easily to fine and very fine granular structure; gradual smooth boundary; some faint clay bridging, but little or no clay films.
C1	31-60"	Predominately yellowish-brown (10YR 5/6) loose fine sand faintly mottled with brownish-yellow, strong-brown, yellow, reddish-yellow, yellowish-red, yellowish-brown and red; structureless; different colors are in strata or streaks. Few fine gravel less than 1/16 inch across; no clay films.

Range in Characteristics:

Small spots are included in the mapping unit that are Rumford loamy fine sand. These spots are shown by sand spot symbols on the map. Thickness of the solum ranges from 24" to 40", but is usually less than 30" thick. Texture of the B2t horizon ranges from light fine sandy clay loam to fine sandy loam.

In a natural condition this soil is strongly acid, low to medium in inherent fertility and low in organic matter content. It is easy to work and conserve; leaches moderately readily, and is productive to most crops of the area under good management, which includes high levels of fertility and irrigation.

Permeability is moderate to rapid in the subsoil but very rapid and rapid in the surface and parent material horizons. The A2 and A3 horizon is slightly compact and retards moisture and air movement to a slight extent.

1B1 - Sassafras fsl, gently, sloping, 2-6% slopes differs from 1A1 mainly by having more strongly sloping slopes. Runoff of surface water is more rapid and water supplying capacity for crops is slightly lower. Suitability is similar to 1A1.

1B2 - Sassafras fine sandy loam, eroded, 2-4% slope differs from 1A1 Sassafras fine sandy loam 0-2% slope mainly by having stronger slopes and by being moderately eroded. Fifty percent of the surface soil has been removed by erosion and the plow layer extends into the subsoil in most places.

This soil comprises about 2 acres in the eastern side of the farm and is not as well suited for most agricultural and non-agricultural uses in 1A1 Sassafras fine sandy loam, 0-2% slopes. However, it can be improved by good management.

2A1 - Local colluvium, moderately heavy substratum, 0-2% slopes. This land type comprises 2 small areas on the farm. It occurs in low lying depressional areas associated with the Sassafras soils. It is well to moderately well drained. Surface runoff is slow to very slow and internal drainage is medium to slow. The underlying strata of Coastal Plain materials consist of moderately heavy textured soil and soil materials of sand, silt, and clay of marine origin. The colluvial materials over the underlying soils is less than 20 inches in most places but ranges from 18 to 36 inches.

Following is a profile description of 2A1 - Local colluvium moderately heavy substratum taken with 3-1/4" orchard auger near west side of the farm.

Ap	0-8"	Brown (10YR 4/3) friable loam, with very fine and fine granular structure.
A2 or A3	8-24"	Grayish brown friable loam, with weak fine granular structure, gradual smooth boundary. Few faint mottles of strong brown and yellow brown in lower part.
IIBI	24-38"	Yellowish brown (10YR 5/6) mottled with strong brown and brownish-yellow friable light sandy clay loam, weak fine and medium subangular block structure, few faint, patchy clay films.
IIB2	38-60"	Mottled light brown, strong brown (7YR 5/6) heavy fine sandy clay loam, that gradually grades to clay loam and clay strata in the lower part; slightly sticky and slightly plastic in the lower part.

The underlying strata are variable in thickness and texture ranging from sandy clay loam to clays. The surface soil ranges from 18" to 28" thick.

This land type is strongly acid in natural conditions and low in essential plant nutrients and low to medium in organic matter content. It is easy to work and erosion hazard is very slight. In fact, there is some deposition from higher lying slopes. It is highly productive of many crops under good management; including high levels of essential plant nutrients and lime. This land type usually retains more moisture than the surrounding Sassafras soils and is less droughty.

<u>3A1 - Sassafras fine sandy loam; heavy subsoil varient, 0-2% slopes.</u> This soil is a deep well drained brownish soil which has formed in moderately

fine textured marine sediments of the lower Coastal Plains region. It differs from 1A1 Sassafras fine sandy loam, 0-2% slopes mainly by having 6-10" thicker subsoils and being a heavy fine sandy clay loam in the subsoil rather than a light fine sandy clay loam. This soil comprises a rather large acreage in the south western part of the farm. Base saturation should be similar to Sassafras fine sandy loam or perhaps a little better in the subsoil.

Infiltration of surface water is rapid to moderate rapid, internal drainage is moderate. This soil has a slightly better water holding and moisture supplying capacity than the coarser textured thinner Sassafras fsl. Workability and conservability is good to excellent and erosion hazards are slight.

Following is a profile description of Sassafras fine sandy loam, heavy subsoils varient, taken in the west central part of the farm.

Ap	0-6"	Dark grayish-brown (10YR 4/2) very friable fine sandy loam with weak fine and very fine granular structures.
A3	6-12"	Yellowish-brown (10YR 5/4) friable brown or light fine sandy loam with weak fine subangular blocky structure. The weak structure peds crush easily to fine granular structure; clear smooth boundary.
B21t	12-24"	Strong brown (7.5YR 5/4) friable to slightly firm, slightly sticky, slightly plastic, heavy fine sandy clay loam; weak fine and medium subangular blocky structure; smooth clear boundary.
B22t	24-40"	Brown to strong brown (10YR 5/3) friable, slightly sticky, slightly plastic, sandy clay loam with weak fine and medium subangular blocky structure, smooth clear boundary.

C1	40-56"	Light yellowish-brown (10YR 6/4) slightly sticky sandy loam faintly mottled with strong brown (7.0 5/4) light gray (10YR 6/1), and (10YR 6/3) pale brown. Clear smooth boundary.
C2	56-60"	Light yellowish-brown loose loamy fine sandy, structureless.

Range in Characteristics

3A1 Sassafras fine sandy loam, thick subsoil variant, has the most uniform characteristics of any soil on the farm. However, in the northwestern corner of the farm, near the woods on leased land, the soil has heavy substrata of clay loam where it joins the Bertie and Lenoir soils. Thickness of solum ranges 40 to 56" but is about 50 inches in most places. Thickness of the solum in 1A1 is usually less than 30 inches over sandy strata.

In a natural condition this soil is strongly acid and moderate to low in natural fertility and organic content, but it has been heavily fertilized and properly managed and, therefore, should be in a good state of fertility. It is easy to work and conserve, has a moderate high water holding capacity and moisture supplying capacity for crops. It is highly productive, perhaps the most productive soil on the farm for the crops grown in the area. Permeability is moderate to rapid in the subsoil and rapid to very rapid in the surface soil and substrata. Compaction by farm machinery or distinct plow pan horizons are not as noticeable in this soil as in the coarse 1A1 and 1B1 Sassafras fine sandy loam.

4A1 - Mattapex loam 0-2% slopes, is a deep moderately well drained medium textured soil that has formed in marine deposits of sand, silt, and clays in the central and northwest corner of the farm. Surface runoff is slow to very slow and internal drainage is moderate to slow. The water table rises to

18 to 20 inches of the surface in the soil in wetter periods. Base saturation of the subsoil is less than 35% where the soil has not been limed or heavily fertilized. The clay content of the subsoil is less than 25% in most places but may range from 25-40%.

Following is a description of 4A1 - Mattapex loam 0-2% slopes taken in a small area in the N.W. corner of the farm.

Ap	0-8"	Brown (10YR 4/3) very friable loam, with weak fine and very fine granular structure. Light gray (10YR 7/2) when dry; slightly compacted in lower 2 inches.
B1	8-14"	Light yellowish-brown (10YR 6/4) friable slightly sticky, heavy loam to light fine sandy clay loam, with very weak subangular blocky structures, smooth clear boundary.
B21t	14-19"	Yellowish-brown (10YR 5/6) slightly firm to friable clay loam with weak moderate to fine subangular blocky structure; mottled with few strong brown mottles in the lower part.
B22t	19-27"	Mottled light brown-gray (10YR 6/2) strong brown (7.5YR 5/4), pale brown (10YR 6/3) and brown (10YR 4/3) firm, hard, plastic, sticky, heavy fine sandy clay loam.
B23t	27-36"	Distinctly mottled with grayish-brown, gray, yellowish-brown, yellowish-red, red, and yellow sandy clay loam. (A clay layer about 2 inches thick which was not sampled between 30" and 37").
IIC1	37-52"	Mottled predominantly gray, with red, yellowish-red, yellowish brown and pale brown, mixed sand, loamy sand, clay, and gravelly soil materials. Material is slightly sticky and plastic and stratified.

<u>Range in Characteristics:</u>

4B1 Mattapex loam 0-2% slope is somewhat variable in the thickness and sequence of horizons. Clayey strata, that may or may not be related to the profile, are below 35". The upper part of the profile has formed in translocated or colluvial materials. The thickness of the surface soil ranges to 6" to 12" and the subsoil from 20 to 40". Depth to gray mottlings in the subsoil varies from 18 to 26". Subsoil textures range from heavy sandy clay loam through clay loams to sandy clay in some strata.

In a natural condition this soil is strongly acid, low in natural fertility and organic matter content; however, it is slightly better in these characteristics than the Sassafras soils 1A1. It is fairly easy to work, and very easy to conserve. It has a moderately high water table in wet seasons, and a good moisture holding and supplying capacity for crops. It is too moist for many vegetable crops and especially for alfalfa and others.

<u>5A1 Local alluvium (over clayey sediment) 0-2% slopes</u>. A truly representative profile would be hard to find of this area. This land type comprises about 1-1/2 acres in the central part of the area. It has formed in a depressional area on concave slopes less than 2% in gradient, and has developed in colluvial material which overlie moderately heavy clayey substrata. It is mostly moderately well drained with slow to very slow runoff and slow internal drainage. The water table may rise within 20 inches of the surface in wetter season. It is strongly acid in a natural condition, moderately low in organic matter content and probably has a low base saturation below 50 inches.

Following is a general profile description of 5A1.

Ap	0-8"	Dark grayish-brown (10YR 4/2) very friable loam, with weak fine and very fine granular structure.

B1	8-15"	Brownish-yellow (10YR 6/4 to 6/3 pale brown) loam to heavy fine sandy clay loam, with fine to medium sub-angular blocky structure.
B2t	15-30"	Grayish-brown (10YR 5/2) to dark grayish-brown (10YR 4/2) firm heavy sandy clay loam mottled with faint, small mottles of strong brown, yellowish-red, grayish-brown, slightly plastic, slightly sticky.
B3	30-34"	Mottled with fairly distinct mottles of yellowish-brown strong brown, brownish-yellow, white and light gray slightly plastic, slightly sticky slight fine sandy loam.
IIC1		Mottled gray yellowish-brown and brownish-yellow sandy loam soil material unrelated to profile above; slightly sticky, slightly plastic.

Range in Characteristics:

This land type is very variable in clay content and horizon sequence in the subsoil with layers ranging from sandy clay loam to sticky plastic clays and clay loams. Near the edges of this area it becomes coarser in texture in the subsoil where it joins the Sassafras soil and is finer where it joins the Mattapex soil.

Because of its slow internal drainage and slow runoff it is only fairly easy to work but easily conserved. It leaches slowly and is productive of crops such as corn, soybeans, and mixed hays that are tolerant to more moist conditions. Permeability is rapid in the surface but moderate to slow in the subsoil. It has a narrow range of moisture conditions under which it can be cultivated and is not a good soil for irrigation.

<u>6D1 - Mixed Coastal Plain sediments, 12-20% slopes.</u> This land type comprises a small area just south of the main building. It consists of a hilly area of mixed Coastal Plain sediments of sand, silt, and clays that varies from shallow gravelly areas to clayey areas with little or no profile development.

This area is best suited for forest, close growing grass crop, or for recreation and wildlife areas.

<u>7A1 - Woodstown fine sandy loam, 0-2% slopes.</u> It is a moderately well drained soil associated with the 1A1 Sassafras and 10A1 Bertie soils in the northern part of the farm. It has grayish-brown to brown fine sandy loam surface soil 8"-10" thick that overlie sand and loam strata usually below 36" to 40". Gray mottles usually occur below 20 inches beneath the surface soil indicating where the water rises in wetter periods.

<u>8A1 Sassafras fine sandy loam, thick surfaces, 0-2% slopes.</u> This soil comprises less than an acre in a somewhat depressed area in the north central part of the farm. It is similar to 1A1 Sassafras fine sandy loam differing from it mainly by having thicker (18" to 22") surface horizons and slightly thinner subsoils.

<u>9A1 Lenoir loam 0-2% slopes.</u> This soil is a somehwat poorly drained clayey subsoil that comprises a small acreage in the N.W. corner of the area. It has formed in Coastal Plain sediments consisting of sand, silt, and clay and occupies level relief. No detailed descriptions were taken of this soil but it has grayish-brown loam surfaces 8" to 10" thick and a mottled gray yellowish-brown and strong brown clay subsoil 20" to 40" in thickness. It is underlaid by sandy and clayey substrata usually below 40 inches.

<u>10A1 Bertie loam, 0-2% slopes</u>. This soil is similar to 9A1 Lenoir loam, 0-2% slopes in drainage and use suitability, differing from 9A1 mainly by having slightly coarser textured subsoils. It is easier to drain and needs surface drainage for most uses.

<u>11A1 Bladen loam, 0-2% slopes</u>. This soil is characterized by a dark colored A horizon which is underlain by gray clay subsoils. This soil is very acid and has a low base saturation. The clay content of the B horizon ranges from 30 to 60 percent. This soil is poorly drained and permeability is slow to very slow.

Supplement to Field Boundaries and Forest Type Map

Type 1 - This type is composed mainly of sweet gum (Lignidamber styraciflua L.) water oak (Quercus nigra L.), white oak (Quercus alba L.), southern red oak (Quercus falcata Michx. var. falcata), and less than 35% loblolly pine (Pinus taeda L.). Area south of farm contains a high percentage of pin oak (Quercus palustris Muenchh.) and hickories (Carya spp.). This type shows the widest variation in stand density varying from 40 sq. ft. acre up to 100 sq. ft. Trees generally less than 60' tall.

Type 2 - This type is composed mainly of loblolly pine 50-90'. Most stands have variable mixture of oaks and sweet gum. Some areas have little understory, others have thick understory of dogwood (Cornus floria L.), holly, (Illex spp.), and other species. Stands are dense, from 80-150 BA.

Type 3 - Composed mainly of pure stands of loblolly 20-50'. Stands are of plantation nature. Stand closure is not complete, with sweet gum composing understory and filling failure spots.

Type 4 - Open areas where tree cover is very sparse. Area west of farm is farmed; while other areas are in grass or grass and a few trees.

Type 5 - Two areas of Virginia pine (Pinus Virginiana Mill.) occur surrounding farm. These have high basal area (100-120 sq. ft.). Trees are 50-60' tall which is 10-15' shorter than same aged loblolly and also have much poorer stem and crown development.

Type 6 - This type is composed of scattered large loblolly (60-90') which may have been left as seed trees. Understory, however, is composed largely of sweet gum and oaks (20-30'). Ten to 15 larger trees were left per acre. Basal area less than 60 sq. ft./acre.

Type 7 - This type consists of large mature hardwoods and loblolly pine which has been reduced to a lower basal area (50-90 sq. ft.) by a recent cutting. Sweet gum, water oak, white oak, and red maple (Acer rubrum L.) are the main hardwoods. Trees range from 60-90' tall.

Type 8 - Similar to type six with scattered large loblolly, but understory is composed of Virginia pine.

Type 9 - This is an area of very poorly drained soils. Red maple and black gum (Nyssa sylvatica Marsh.) form almost 100% of the type in some areas. Loblolly pine, water oak, and other hardwoods are scattered throughout type.

Type 10 - This type is found only in one small area south of farm. This area is almost entirely lacking in pine species. Pin oak, hickories, southern red oak, and water oak are main hardwood species. Trees are young and are only 30-50' tall. Stand is dense with a high basal area (80-110).